Nuuk basic

the geobasis programme

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NERO

NUUK ECOLOGICAL RESEARCH OPERATIONS

5th Annual Report 2011

Aarhus University
DCE – Danish Centre for Environment and Energy

NUUK ECOLOGICAL RESEARCH OPERATIONS

5th Annual Report 2011

AARHUS
UNIVERSITY
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Back cover photo: Diapensia (*Diapensia lapponica*) growing on an exposed ridge in the Kobbefjord area, June 2011. Photo: Katrine Raundrup

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Nuuk Ecological Research Operations (NERO) is together with Zackenberg Ecological Research Operations (ZERO) operated as a centre without walls with a number of Danish and Greenlandic institutions involved. The two programmes are gathered under the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in NERO:
Department of Bioscience, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
Greenland Institute of Natural Resources: BioBasis and MarineBasis programmes
Asiaq - Greenland Survey: ClimateBasis programme
University of Copenhagen: GeoBasis programme

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Summary for policies makers

Lillian Magelund Jensen

The 2011 field season in Kobbefjord started 11 January and continued until 12 December. During this period, 33 scientists and logisticians spend 199 and 18 bed nights in the study area, respectively.

In March 2011, the extension of the Greenland Institute of Natural Resources was inaugurated. The building was generously funded by a donation from the Aage V. Jensen Charity Foundation of approximately 33 million DKK.

In June 2011, a bridge across the river Kobbefjord was constructed. Asiaq – Greenland Survey, generously donated the bridge.

Nuuk Ecological Research Operation is involved in several larger international research projects. Greenland Ecosystem Monitoring (GEM) is involved in the EU projects 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT) and 'Svalbard Integrated Arctic Earth Observing System' (SIOS).

INTERACT has a transnational access component, which from 2011 allows foreign scientists to visit the stations (45) involved in the network free of charge. Greenland Institute of Natural Resources has been allocated 353 bed nights for transnational access during the period 2011-14. In 2011, two projects received support for 50 bed nights from INTERACT transnational access.

Results from the Nuuk Basic monitoring programme are continuously published in scientific papers and popular science articles. Furthermore, data from the Nuuk Basic programme is freely available and was in 2011 used for reporting purposes in a number of international fora and by a number of externally funded research projects.

In 2011, more than twelve scientific papers were publish by the researchers from the Nuuk Basic programme and from externally funded research projects.

In 2011, the Greenland Ecosystem Monitoring Coordination Group has produced a strategy and working programme for Greenland Ecosystem Monitoring 2011-15 describing in details how the goals of the strategy will be achieved. Among the overall changes were inclusion of upscaling of climate change effects to Greenlandic scale and two new stations – Arctic Station and Sermilik Station.

Executive summary

Mark Andrew Pernosky, Birger Ulf Hansen, Peter Aastrup, Thomas Juul-Pedersen and Lillian Magelund Jensen

Introduction

The year 2011 was the fifth year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was the third year with complete annual time series for all sub-programmes.

ClimateBasis

The ClimateBasis programme gathers and accumulates data describing the climatological and hydrological conditions in the Kobbefjord area. Data are measured by two automatic climate stations (C1 and C2), two automatic hydrometric stations (H1 and H2), and three diver stations (H3, H4 and H5). Data are daily transferred from station C1, C2 and H1 to Asiaq via radio link and GMS modem.

The two climate stations are placed next to each other to ensure data continuity. Sixteen climate parameters are monitored and data stored in the database, including two derived parameters.

The mean annual air temperature in 2011 was -1.6 °C, which is the coldest recorded annual air temperature measured in the Kobbefjord area since the start of the programme. In addition, the period with continuously daily mean air temperature above 0 °C started later than seen in previous years, nine days later than 2008, six days later than 2009 and 24 days later than 2010 (which was an extremely warm year).

In the Kobbefjord area, measurement of water level and discharge started in 2006 at H1, at H2, H3 and H4 in 2007 and at H5 in 2008. Manual measurements of discharge were in 2011 continued at H1, H3, H4 and H5. H1 and H2 are measuring throughout the year, while measurements at H3, H4 and H5 starts up in early spring when the rivers are free of snow and ice, and ends in late fall before the river freezes.

In 2009, a final Q/h-relation was established, incorporating discharge measurements over nearly the entire recorded water levels. This Q/h-relation has been upgraded to take account for periods where the outlet is affected by snow and/or ice. For H2, H3, H4 and H5 there still is a lack of discharge measurements at high water levels to establish reliable Q/h-relations.

For H1, which is placed at the main river in the Kobbefjord area, the total discharge during the hydrological year 2010/2011 was 34.4 million m^3. The peak discharge in 2011 was recorded 9 June and was caused by a combination of melting snow pack and precipitation.

GeoBasis

The 2011 season was the fourth full season for the GeoBasis programme with a field season from May to late October. Data collected by the Danish Meteorological Institute shows that 2011 was colder than normal in Nuuk. The annual mean air temperature in Nuuk reached -1.7 °C, which is 0.3 °C colder than normal. Eight months were colder than normal, while January, June, July and August were warmer than normal. Especially April was cold with an average monthly temperature of -8.6 °C, which makes it the second coldest since the air temperature measurements were initiated in 1866 only exceeded by -9.1 °C registered in 1949.

The melting of snow and ice in the Kobbefjord area started in the beginning of May and by mid-June, all snow on the east side of the main river outlet had melted. The break-up of the ice covers on the lakes was approximately one to two weeks later than in previous years.

When comparing the snow cover survey in 2011 with previous years, the snow depth on the three locations is similar to 2009, but much higher compared to 2010.

At the micrometeorological station in the Kobbefjord area, the mean monthly air temperature was 8.2 °C at SoilFen station in August compared to 8.7 °C in 2009 and 11.3 °C in August 2010. At M500 the mean monthly air temperature in August was 8.2 °C in August 2011 compared to 7.1 °C in 2009 and 9.0 °C in 2010.

At the three automatic soil stations in the area; SoilFen, SoilEmp and SoilEmpSa the soil inter-annual temperature variations in 2011 were quite similar to those documented in previous years although the colder climate in 2011 causes an average soil temperature of only 2.3 °C compared to 3.7 °C in 2010 and 2.8 °C in 2009.

In 2011, sixty soil water samples were collected from two depths at the SoilFen site and the SoilEmp site. In August 2010, laboratory equipment was installed in the research cabin, which enabled analyses of soil water alkalinity, pH, temperature and conductivity.

In 2011, *in situ* measurements of river water temperature, conductivity and pH were carried out along with the collection of 40 water samples from mid-May to mid-October, the field season being one month shorter than previous years due to the late snow and ice melt. The minimum water temperature of 0.4-0.5 °C was measured at the beginning of the season and reaching a maximum of 13.3 °C in mid-August, both minimum and maximum occurring one month later than previous years due to the late snow melt. The conductivity shows a significant decrease within the snow melting period (May-June) to a level of 18 +/- 1.5 µSc m^{-1}, while pH shows a constant level of 6.8 +/- 0.4 from May to October 2011.

Due to the late onset of CH_4 flux measurements in 2011, the flux dynamics during early growing season cannot be described. There was a peak in CH_4 emission in early August, amounting to approximately 4 mg CH_4 m^{-2} h^{-1}. This peak level is comparable to 2008 and 2010, but lower than in 2009. The peak occurred later than previous years, most likely due to the late snow melt in 2011. After the peak, emissions decreased to below 1 mg CH_4 m^{-2} h^{-1} in October. Overall, the observed temporal CH_4 flux pattern of the Kobbefjord fen displays low shoulder season emissions with a dome-shaped peak during the growing season.

Measurements of the temporal variation in daily net exchange of CO_2 were initiated 15 May and continued until 14 October 2011. The period with net CO_2 uptake in 2011 lasted until 7 September, which was the latest ending on record. During this period, the fen accumulated -14.3 g C m^{-2}, and maximum daily accumulation rate amounted to -1.6 g C m^{-2} (measured 18 August). The CO_2 accumulation during the net CO_2 uptake period in 2011 was lower than in previous years, which is likely caused by late snow melt and onset of growing season in combination with low levels of photosynthetic active radiation. During the entire measuring period (152 days) the fen constituted a fairly strong source for atmospheric CO_2, amounting to 42.6 g C m^2.

In 2011, GeoBasis installed two new energy balance stations in cooperation with an INTERACT project. The stations were located at a new site in the heath vegetation and at the fen site, respectively.

BioBasis

The 2011 season was the fourth full season for the BioBasis monitoring programme. Generally, there is a high consistency in data collected during the four years indicating that the data and the procedures used are reliable and sound.

A preliminary review of data related to flowering and plant reproductive phenology indicates that 2011 was characterised by late flowering, an extreme impact of the noctuid moth, *Eurois occulta*, and no re-budding events in *Loiseleuria procumbens* and *Silene acaulis.* The year 2011 had a late melt-off of snow so the recording period covers early June to early October. *Loiseleuria procumbens* flowered one month later than the earliest year 2010.

The buds of all the monitored species were heavily impacted by larvae of the noctuid moth, *Eurois occulta*. This is the second year in a row with impact of this moth species. The number of larvae peaked in early July with nearly 2000 trapped during one week. Because of the larvae impact, it was only possible to record the time of 50 % flowering in one of the monitoring species. It is the latest date of 50 % flowering ever recorded for *Silene acaulis* during the years of monitoring. The maximum number of buds of *Loiseleuria procumbens* is the largest number recorded since the monitoring programme started but all were eaten and no re-budding occurred later in the season. All the catkins of *Salix glauca* were eaten by the moth larvae. Consequently, the seed production was at a minimum this year.

Generally, the NDVI (Normalized Difference Vegetation Index) values in the permanent plots were significantly lower for *Empetrum nigrum*, *Eriophorum angustifolium*, and *Salix glauca* and they peaked later at the end of the growing season compared to previous years. The lower values are presumably caused by the heavy impact of the larvae.

Generally, the NDVI values along the NERO line in the heaths and the copses were lower than the previous years, especially in the beginning of the season and reached the level from previous years in late August. The NDVI values peaked in the heaths by the end of the season. The fen plot reached the peak of NDVI later than in previous seasons and the greening was slower in the beginning of the growing season presumably due to the late snow melt.

Generally, all plots functioned as sinks for atmospheric CO_2 in August and September, whereas fluxes were close to zero in June, July and October. Similar to earlier years NEE (Net Ecosystem Exchange) is more negative in C-plots (control) compared with T- and S-plots (increased temperature and shading, respectively). The ecosystem respiration showed a constant pattern of higher emissions in T-plots compared with other treatments, which can be explained by warmer and drier conditions leading to increased respiration rates. The highest rates of gross primary production were generally observed in C-plots, while especially S-plots showed lower GPP (Gross Primary Production) rates compared with other treatments.

In general, there are huge variations in the number of trapped arthropod specimen within all taxonomical groups both within the season and between years. The peak number of specimens trapped is often reached in the beginning of the season. The most abundant group is Acarina, which peaks with more than 160 specimens trapped during one week.

A microarthropods and arthropod isotope campaign was implemented in 2011 as an increasing number of studies have applied analysis of natural abundance of stable isotopes to soil invertebrate communities and primary producers. Soil, turf and detritus were sampled for determination of natural abundance of stable isotopes in invertebrates.

The most common bird species were Lapland bunting and snow bunting as observed in previous years and there was a slight increase in numbers of Lapland bunting, snow bunting and northern wheatear over the years. There has been a decline in the numbers of redpolls since 2009.

Both Badesø and Qassi-sø are oligotrophic lakes. However, nitrogen level has been increasing during the past four years, except for the dry year 2009, where the nitrogen level was very low, probably due to a reduced nutrient run-off. During the four-year period, a slight increase in chlorophyll *a* and consequently a small decrease in Secchi depth have been observed. The decrease in Secchi depth has not affected macrophyte growth. The depth limit of the macrophyte growth is slowly increasing particularly in Qassi-sø. The zooplankton community and biomass reflects the conditions in the two lakes. We find a higher zooplankton biomass in the Qassi-sø (without fish) indicating a small predation pressure on zooplankton and consequently a slightly lower phytoplankton/zooplankton ratio compared to Badesø, which has fish and therefore a higher predation pressure on zooplankton.

MarineBasis

The MarineBasis programme is running on its sixth year. The programme incorporates a broad spectrum of parameters covering sea ice conditions, physical and chemical oceanography and biological components from the water column and sediments along with observations of higher trophic levels such as seabirds and whales. The aim of the programme is to establish long-time series of key parameters of a high latitude marine ecosystem, thereby improving knowledge on natural variability of these systems and enable identification of climate related changes.

Sea ice conditions in the Baffin Bay during the first half of 2011 resembled previous years with maximum coverage occurring late May, while the onset of sea ice build-up appeared to start later. Sea ice was only observed in the inner branches of the Godthåbsfjord system, which is similar to previous years. Ice, i.e. glacial and sea ice, melts locally or is exported from the fjord in seasonal bursts. A strong burst in ice and melt water affected conditions at the sampling station near the fjord entrance during sampling in late April.

Monthly hydrographical profiles at the permanent sampling station combined with annual length and cross sections of the Godthåbsfjord system showed overall seasonal hydrographically conditions comparable to previous years. A warm saline inflow of nutrient rich coastal water entered the fjord early in the year (i.e. winter). Except for a confined burst in ice and melt water in late April, spring condition was characterized by a rather homogenous water column due to vertical mixing. The burst in ice and melt water in late April also depicted the highest phytoplankton biomass and production rates recorded throughout the programme. Moreover, the annually integrated phytoplankton production was the highest recorded since 2006. Increase in melt water and solar heating of the surface water produced a stratification of the upper part of the water column, which withstood the vertical tidal mixing. Phytoplankton production during spring and summer depleted nutrients concentrations within the surface layer, as observed in previous years.

The phytoplankton community was apparently also affected by the burst in ice and melt water as diatoms dominated in late April, rather than *Phaeocystis* sp. (*Haptophyceae*) as observed in previous years except in 2009. *Phaeocystis* sp. only dominated in June, later than in previous years. Autumn condition resembled previous years. Zooplankton, i.e. copepods and other groups, depicted low abundances throughout the year, compared to previous years. The copepod community was also in 2011 dominated by *Microsetella norvegica*, except in July when *Oithona* spp. was unusually abundant. Fish larvae show considerable inter-annual variability, but sand eel larvae have almost disappeared from the samples while capelin and Arctic shanny larvae were caught in 2009 and 2011. In addition, Atlantic cod and American plaice larvae increased in numbers, showing the highest recorded abundances. Nevertheless, low numbers of fish larvae were generally observed throughout the year. Similar to previous years, shellfish larvae showed a seasonal peak of *Pandalus* sp. in April and of *Chionoecetes opilio* and *Hyas sp*. in May. While *Pandalus* sp. and *C. opilio* have no clear overall temporal trend, *Hyas sp*. has been increasing in numbers since 2008. Jellyfish was less abundant compared to previous years and only present during winter and spring (i.e. January to April).

The previously described early peak in phytoplankton biomass and production in late April, due to a burst of ice and melt water, also resulted in high rates of vertical sinking flux of particulate material. Another occurrence of high fluxes in September also corresponded with a burst of ice from the inner part of the fjord. Seasonal differences in phytoplankton production are also reflected in the sinking material, with fresher material in spring and summer. The organic material reaching the benthos also seems to have induced high oxygen consumption within the sediment, particularly during summer and autumn where sediment studies indicated high faunal activity. Sea urchins showed the lowest gonad index recorded, while the index of scallops was close to average. Moreover, scallops showed the highest conditions index recorded. While the macroalgae *Laminaria latissima* showed no clear trend in the annual growth measured as blade length, there is an increasing trend in the biomass measured as blade biomass although this may be due to low values in 2007. Different ice conditions between sampling sites in the fjord did not seem to affect the growth significantly. However, there was a higher C/N ratio of the blades from the area protected from sea ice, and C/N ratio did also show a generally negative trend since 2007. The C/N depicts the nutritional condition of the macroalgae.

Two major seabird colonies near Nuuk are monitored for the MarineBasis programme; additional colonies are, however, also included. The land-based survey at one of the major colonies (Qeqertannguit) was delayed in 2011 due to snow cover. Kittiwakes showed the highest numbers since 2006 whereas Iceland gulls were similar to previous years. For the first time no Arctic skuas were recorded and Arctic terns have only been observed in low numbers and with none in recent years. At the other major colony (Nunngarussuit), the number of guillemots appears largely unchanged in the past couple of years. For the other kittiwake colonies, an increase was observed in the number of breeding pairs, except for the Alleruusat colony.

The whale photo identification programme resulted in identification of 19 different humpback whales in Godthåbsfjord during 2011, and 11 of these had been observed in the fjord system in previous years. In addition, about one third of the whales identified in 2011 was also identified in the fjord the year before. The photo identification programme shows that certain whales have high site fidelity, returning to Godthåbsfjord and staying longer to feed.

Research projects

In 2011, five different research projects were carried out in cooperation with Nuuk Ecological Research Operations. The research projects focused on different biological topics in the limnic and terrestrial compartment of the ecosystem. The research projects are presented in Chapter 6.

1 Introduction

Lillian Magelund Jensen

The year 2011 was the fifth year of operation of the fully implemented Nuuk Basic programme (including both a terrestrial and a marine component), and it was the third year with complete annual time series for all sub-programmes.

The 2011 field season in the Kobbefjord area started 11 January and continued until 12 December. During this period 33 scientists and logisticians spent 199 and 18 'man-days' in the study area, respectively.

1.1 Funding

Nuuk Basic is funded by the Danish Energy Agency and the Environmental Protection Agency with contributions from Greenland Institute of Natural Resources, Asiaq – Greenland Survey, Aarhus University and University of Copenhagen. Aage V. Jensen Charity Foundation has generously provided most of the necessary research infrastructure, including boats, research hut, office and accommodation facilities at Greenland Institute of Natural Resources.

1.2 Greenland Institute of Natural Resources and Greenland Climate Research Centre

In March 2011, the extension of the Institute of Natural Resources was inaugurated. The new addition (approximately 820 m^2) contains office space for 25 employees, meeting rooms, laboratories, storage room, bicycle storage and a lounge area. The building was generously funded by a donation from the Aage V. Jensen Charity Foundation of approximately 33 million DKK. The donation also includes furniture, new freezing facilities, conference facility and renovation of the main building.

1.3 Bridge across the river Kobbefjord

In June 2011, a bridge across the river Kobbefjord was constructed. Asiaq – Greenland Survey, generously donated the bridge.

1.4 International cooperation

Nuuk Ecological Research Operation is involved in several larger international research projects. Greenland Ecosystem Monitoring (GEM) is involved in the EU projects 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT) and 'Svalbard Integrated Arctic Earth Observing System' (SIOS).

INTERACT has a transnational access component, which from 2011 allows foreign scientists to visit the stations (45) involved in the network free of charge. Greenland Institute of Natural Resources has been allocated 353 bed nights for transnational access during the period 2011-14. In 2011, two projects received support for 50 bed nights from INTERACT Transnational Access.

SIOS is a network of different organizations working with earth observations on Svalbard and in its nearest surrounding.

In January 2001, Canada Excellence Research Chair in Arctic Geomicrobiology and Climate Change/Centre for Earth and Observation Sciences at University of Manitoba, Canada, and Arctic Research Centre (in planning) at Aarhus University, Denmark, held a three day meeting in Winnipeg, Canada, regarding a future formal collaboration on science, monitoring and education. The cooperation is named Arctic Science Partnership (ASP) and will focus on climate, cryosphere, ecosystem and human interactions.

In October 2011, Professor Bo Elberling from University of Copenhagen received funding for a new Centre of Excellence – Centre for Permafrost (CENPERM). The overall objective of CENPERM is to provide new insight into the complex interactions going on between microbial activity, plant growth and soil structure when permafrost thaws. CENPERM will focus on permafrost thawing in Greenland and will take a multidisciplinary approach and investigate the biological, geographical and physical effects of permafrost – in the short and in the long term. The centre will have four Greenland Ecosystem Monitoring field sites at Nuuk, Sermilik, Disko Island and Zackenberg among its most important study sites.

In 2012, Aarhus University will establish an Arctic Research Centre (ARC). The centre will be established as an interdisciplinary centre across the main academic areas, Science and Technology, and Health. The Centre is to be a partner in the Arctic Science Partnership (ASP) and to have strong collaborative ties with the Greenland Institute of Natural Resources in Nuuk and University of Manitoba, Canada.

1.5 Greenland Ecosystem Monitoring Strategy 2011-15

Late in 2010, the Greenland Ecosystem Monitoring Steering Committee approved a strategy for Greenland Ecosystem Monitoring 2011-15. The strategy includes thirteen different research questions to be addressed during 2011-15. In 2011, the Greenland Ecosystem Monitoring Coordination Group produced a strategy and working programme for Greenland Ecosystem Monitoring 2011-15 describing in details how the goals of the strategy will be achieved. Among the overall changes were inclusion of upscaling of climate change effects to Greenlandic scale and two new stations – Arctic Station and Sermilik Station. The Greenland Ecosystem Monitoring Strategy and Working Programme 2011-15 can be downloaded from www.nuuk-basic.dk and www.g-e-m.dk or a hard copy can be ordered free of charge from the Nuuk Basic secretariat (nuuk-basic@dmu.dk).

1.6 Further information

Further information about the Nuuk Ecological Research Operations (NERO) programme is collected in previous annual reports (Jensen and Rasch 2008, 2009, 2010 and 2011). Much more information is available on the NERO website: www.nuuk-basic.dk including manuals for the different monitoring programmes, a database holding data from the monitoring, up-to-date weather information, a NERO bibliography and a collection of public outreach papers in PDF-format.

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2 NUUK BASIC

ClimateBasis Programme

Mark Andrew Pernosky, Kenneth Hill, Per Hangaard, Morten Larsen, Kisser Thorsøe, Dorthe Petersen and Maria Knudsen

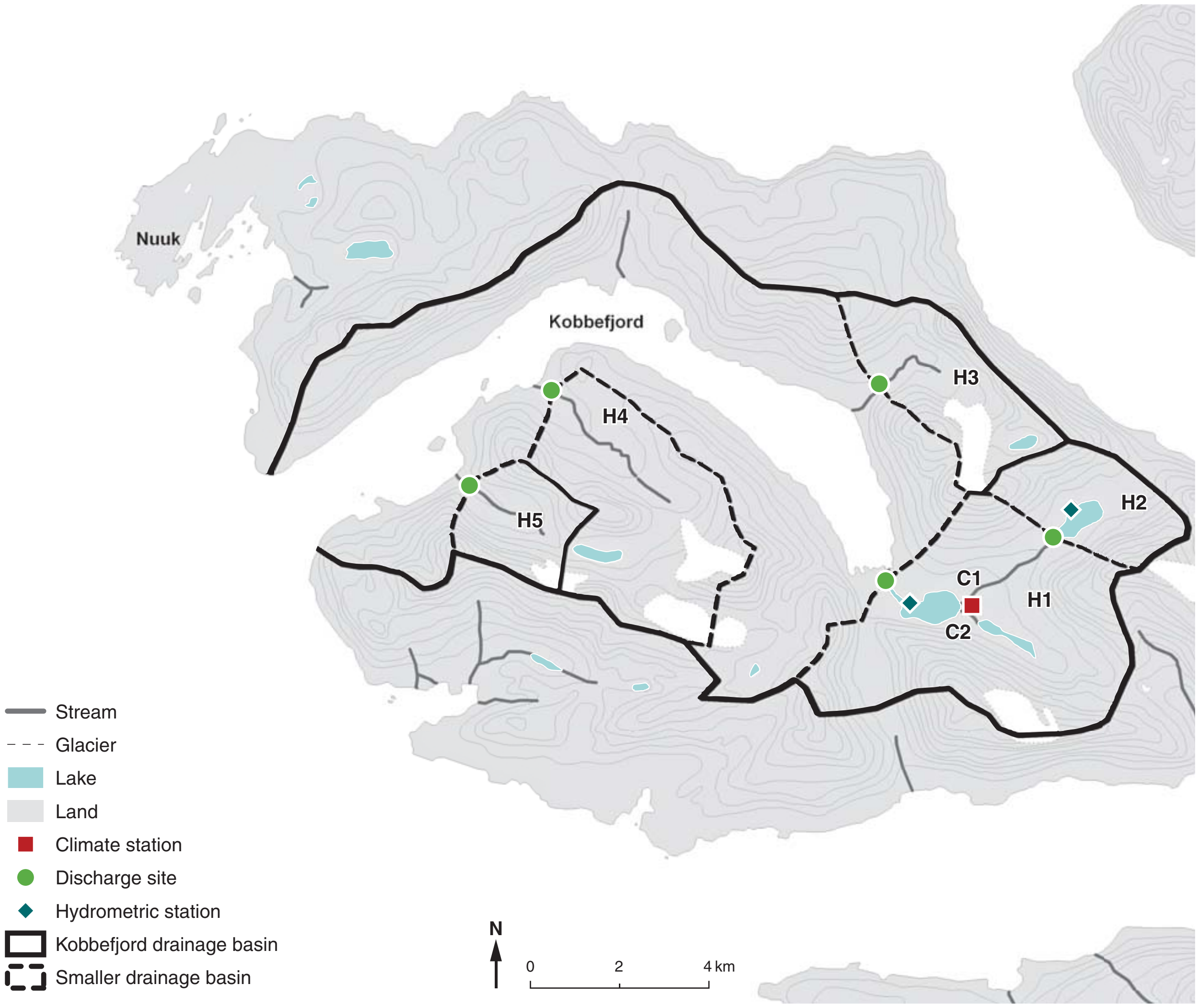
The ClimateBasis programme gathers and accumulates data describing the climatological and hydrological conditions in the Kobbefjord area. Two automatic climate stations, C1 and C2, two automatic hydrometric stations, H1 and H2, and three diver stations, H3, H4 and H5, are monitoring physical parameters necessary to describe variations in climate and hydrology. Location of the different stations can be seen in figure 2.1. ClimateBasis is operated by Asiaq – Greenland Survey.

During 2011, further work was made to facilitate automatic data retrieval from Nuuk, and the system was made operational during 2011. Data from the stations H1, C1 and C2 is sent via radio link to the ClimateBasis/GeoBasis station M1000. From M1000 data is sent to Nuuk via GSM modem.

2.1 Meteorological data

In 2011, the climate stations in the Kobbefjord area were visited three times by Asiaq technicians and five times by other Asiaq personnel. The maintenance of the stations included reference tests of important

Figure 2.1 Location of the climate (C1, C2), hydrometric (H1, H2) and diver stations (H3, H4, H5) in the Kobbefjord area together with the drainage basins of Kobbefjord and the drainage basin for the hydrometric stations and the diver stations.



parameters, and replacement of the wind speed/wind direction sensor at 10 m, the snow depth sensor at station C1 and the wind speed sensor at 2 m at station C2. Furthermore, a wind generator was added as an additional energy source. A full description of the climate stations are given in Jensen and Rasch 2008.

During the quality control of meteorological data an improved method for quality control of both Albedo and Normalized Differential Vegetation Index (NDVI) has been used on data for 2011, see Pernosky et al. 2012. Data from previous years has been re-evaluated and sent to the Nuuk Basic database at the Department of Bioscience, Aarhus University.

Meteorological data 2011

This annual report describes the fourth full year of data for climate parameters and refers to data collected during the period from 1 January to 31 December 2011. Figure 2.2 gives an overview of selected meteorological parameters in 2011.

The annual mean of recorded temperatures in 2011 was -1.6 °C, table 2.1. The coldest month was April with an average temperature of -9.5 °C and a minimum temperature as low as -24.2 °C. The warmest month was July with temperatures averaging 10.0 °C; however, the maximum temperature occurred 30 June measuring 19.3 °C. Compared with the climate normal for Nuuk (1961-90) the recorded annual

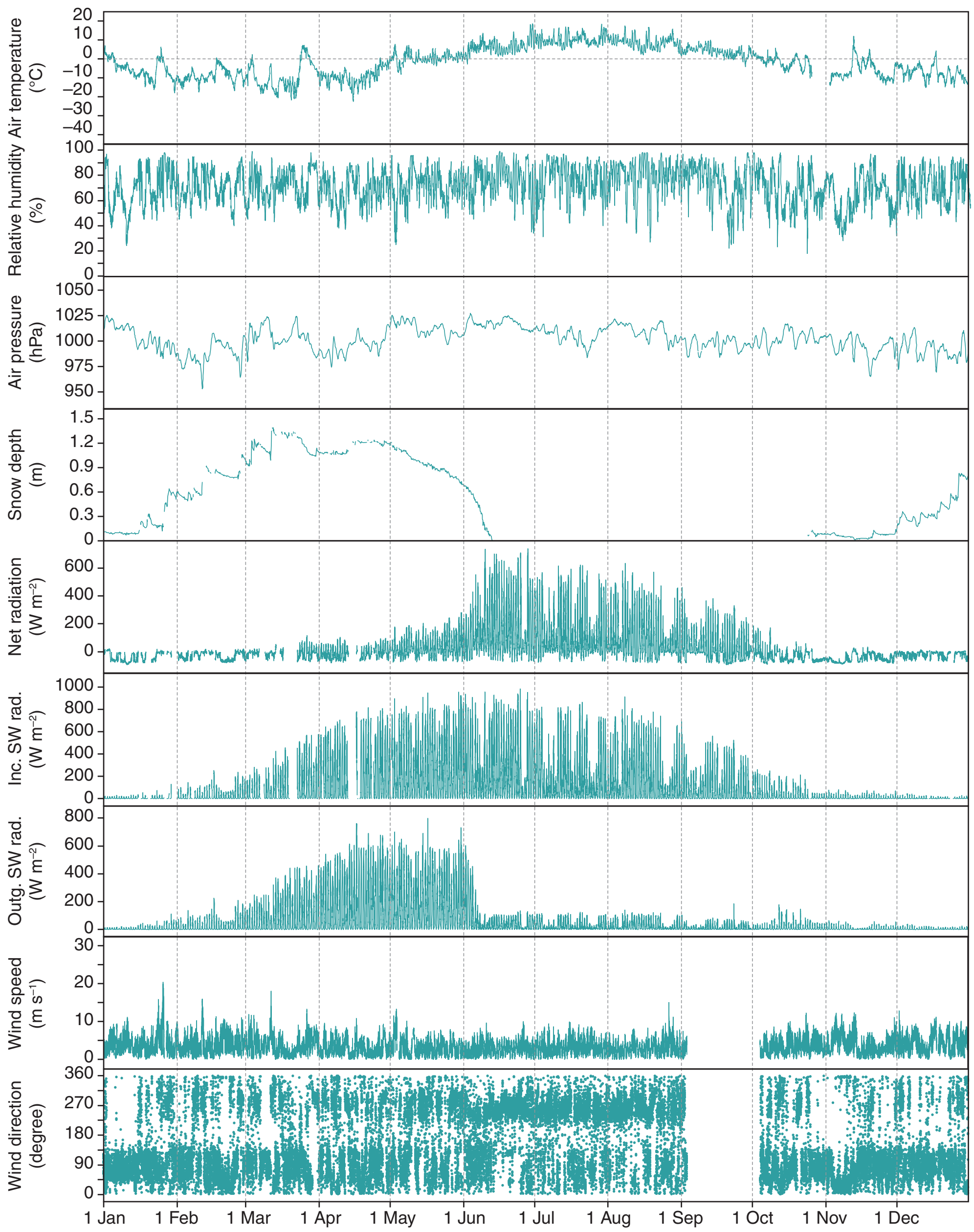


Figure 2.2 Variation of selected climate parameters in 2011. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation, outgoing short wave radiation, wind speed and wind direction. Wind speed and direction are measured 10 m above terrain; the remaining parameters are measured 2 m above terrain.

Table 2.1 Monthly mean values of selected climate parameters from January to December 2011.

Month	Rel. hum. (%)	Snow depth (m)	Air temp. (°C)	Air pressure (hPa)	Precip. (mm)	Wind ($m\ s^{-1}$)	Wind dir. (most frequent)
Jan	69	0.21	-5.4	1004	–	4.1	ENE
Feb	72	0.73	-8.7	987	–	4.0	NE
Mar	72	1.18	-9.2	1005	–	3.7	ESE
Apr	69	1.15	-9.5	995	26.5	3.0	WNW
May	72	0.96	0.3	1012	8.5	3.2	WNW
Jun	76	0.17	6.2	1017	43.6	2.7	WSW
Jul	77	–	10.0	1006	60.1	3.2	WSW
Aug	79	–	8.7	1010	88.9	3.0	WSW
Sep	75	–	3.9	997	70.1	–	–
Oct	69	–	-2.4	1003	46.9	3.6	NE
Nov	64	0.06	-6.2	994	41.5	3.9	NE
Dec	72	0.41	-7.5	992	112.6	4.3	ESE
2011	72	–	-1.6	1002	–	3.5	–

Months with data coverage of less than 80% have been omitted.

mean temperature in the Kobbefjord area during 2011 was below normal, as well as the recorded month mean temperatures for February to April and October to December (Cappelen et al. 2001). Comparing average monthly temperatures from the Kobbefjord area with Nuuk from 2008 to 2011 shows that temperatures in the Kobbefjord area are typically colder than Nuuk during winter months and warmer than Nuuk during summer months, figure 2.3.

The general weather pattern from January to March 2011 was characterized by long periods with easterly winds and temperatures ranging from -22 °C to 7 °C. Occasional storms brought stronger winds from the WNW and precipitation, often with significant increases in temperature. Snow cover in the Kobbefjord area began with a meagre 10 cm at the start of 2011; however, by the end of February over 1 meter of snow was measured at the climate stations. On 13 March, a maximum snow depth of 1.39 m was reached. The snow pack compressed to 1.26 m before a rain-on-snow event at the end of March. The days between 25 March to 28 March recorded average daily temperatures above 0 °C and by 31 March, the snow pack had been reduced to 1.04 m.

The remaining part of spring was cold in the Kobbefjord area during 2011. The average monthly temperature in April was -9.5 °C, the coldest of any month during 2011 and 8.1 °C colder than the average temperature for April during 2008-2010, table 2.2. Snow depths increased slightly in

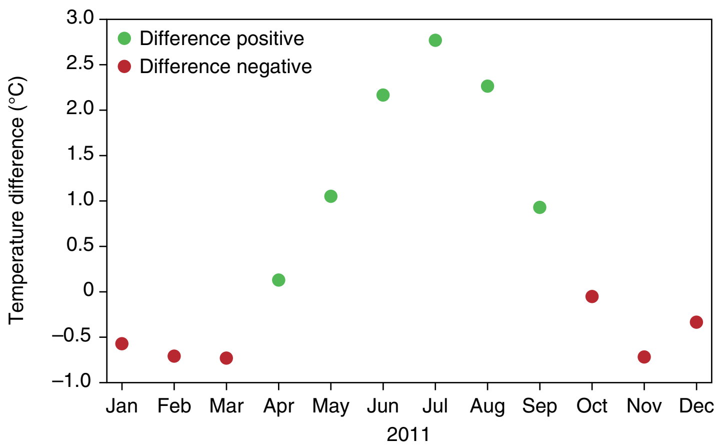


Figure 2.3 Difference in monthly average temperature between the Kobbefjord area and Nuuk 2008-2011.

Table 2.2 Comparison of monthly mean air temperatures 2007 to 2011 (italicized text represents months with incomplete coverage).

	Air temperature (°C)				
Month	**2007**	**2008**	**2009**	**2010**	**2011**
Jan	–	-12.0	-5.4	-3.8	-5.4
Feb	–	-13.3	-6.1	-1.6	-8.7
March	–	-8.3	-11.7	-4.5	-9.2
April	–	-0.9	-3.2	-0.1	-9.5
May	*0.6*	3.9	0.3	7.1	0.3
June	*5.3*	7.9	6.4	8.8	6.2
July	*10.8*	10.9	10.6	10.7	10.0
August	10.6	8.7	9.3	11.7	8.7
September	4.0	4.4	3.8	7.8	3.9
October	-0.5	0.0	-0.6	2.9	-2.4
November	-3.5	-1.7	-7.9	1.2	-6.2
December	-8.7	-7.8	-2.8	0.5	-7.5
Year	**–**	**-0.7**	**-0.6**	**3.4**	**-1.6**

Table 2.3 Monthly mean values of selected radiation parameters in 2011.

Month	NDVI	Albedo	Short wave rad (W m-2) in	Short wave rad (W m-2) out	Long wave rad. (W m-2) in	Long wave rad. (W m-2) out	Net rad. (W m-2)	PAR (µmol s-1 m-2)	UVB (mW m-2)
Jan	–	–	–	4.1	–	277	–	10.1	0.2
Feb	–	0.92	20.4	18.3	–	261	–	46.9	0.9
Mar	-0.09	–	–	65.9	–	262	–	154	4.5
Apr	-0.05	–	–	170.0	–	262	–	412	11.1
May	-0.09	0.76	248	186.0	272	308	26	565	22.9
Jun	0.12	0.22	239	55.0	302	351	135	538	25.9
Jul	0.18	0.13	169	22.9	329	373	103	381	18.5
Aug	0.23	0.14	154	22.6	318	366	82.9	338	14.3
Sep	0.29	–	74.3	10.7	288	330	21.5	165	7.4
Oct	–	0.66	25.2	12.3	245	290	-32.3	60.0	2.5
Nov	–	0.73	6.8	5.1	224	272	-45.4	17.9	0.4
Dec	–	0.92	2.3	2.1	251	271	-20.6	5.2	0.1

Months with data coverage of less than 80% have been omitted.

April to 1.21 m and remained stable from 15 April to 29 April. Melting of the snow pack began slowly 30 April. In addition, the dominate wind direction began to shift to a westerly wind throughout April. The month of May was very dry with only 8.5 mm of precipitation. As a result, most of the snow melt was a result of increased temperatures and not due to rain events. Between 2 May and 5 June, the snow pack decreased steadily at a rate between 1 and 4 cm per day. Between 5 and 14 June, the rate of melting increased, with a maximum melt rate of 12 cm per day. The last day with a mean air temperature below the freezing point was 22 May. This is nine days later than the average of 2008 and 2009, and the latest day since the measurements began in the Kobbefjord area in 2007.

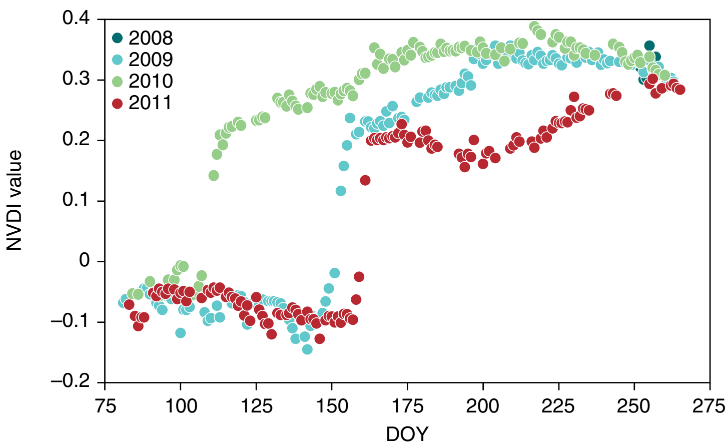
During the entire summer, the dominating wind direction continued to be a westerly wind. Air temperatures throughout the summer remained close to previous years although in the colder end of the spectrum. Temperatures in July have been very stable the past five years, not varying more than 0.9 °C, table 2.2. Precipitation increased from June to August, with August matching the climate normal for Nuuk (Cappelen et al. 2001). Although the precipitation amounts are considered normal, most of the precipitation in August came with a passing low-pressure system where over 64 mm precipitation fell within 21 hours and wind speeds reached up to 15 m s^{-1}.

Between September and October, the dominate wind direction shifted back to an easterly direction. Air temperatures steadily decreased during the autumn with no significant föhn events until a passing low-pressure system 12 November. Between 11 November 20:00 and 12 November 20:00 the air temperature increased by 21.2 °C. However, from October to December the 10 minute average wind speed did not exceed 13 m s^{-1}, which is low for the Kobbefjord area compared to previous years where wind speeds over 15 m s^{-1} have been measured on several occasions.

The first day with a mean daily temperature below 0 °C was 28 September, which is only one day later than the average of 2007-2009 but exactly one month earlier than 2010. Snow was first recorded at the climate stations 13 October and the permanent snow cover at the climate stations started 24 October.

The levels of selected radiation parameters are displayed in table 2.3. The vegetation underneath the radiation masts did

Figure 2.4 NDVI measured at the climate masts since 2008.



not green as much as previous years, with the highest daily Normalized Differential Vegetation Index (NDVI) value, recorded 13 September, of 0.30. This differs from a maximum daily NDVI value of 0.36 in 2009 and 0.39 in 2010, figure 2.4. Due to the snow pack lasting late into the spring, high values of outgoing short wave radiation were measured in both April and May.

2.2 River water discharge

Hydrometric stations

In 2011, hydrological measurements were carried out at five locations in the Kobbefjord area. Two hydrometric stations were established in 2007 and divers are each year deployed in three minor rivulets to Kobbefjord. The drainage basins of the five locations cover 58 km² corresponding to 56 % of the 115 km² catchment area to Kobbefjord.

In figure 2.1, the location of the hydrometric stations (H1, H2) and the diver stations (H3, H4, H5) can be seen. For further descriptions of the stations and their respective drainage area, see Jensen and Rasch 2009. For descriptions of the hydrometric stations, see Jensen and Rasch 2008.

Q/h-relation

Manual discharge measurements have been carried out at station H1, H3, H4 and H5 (respectively three, six, one and four times) during 2011. The purpose is to establish and validate a stage-discharge relation (Q/h-relation). It is generally recommended to base a Q/h-relation on a minimum of 12-15 discharge measurements covering the water levels normally observed at the station (ISO 1100-2 1998). For H2, H3, H4 and H5 not enough discharge measurements have been carried out, especially at high water levels, to produce reliable Q/h-relations. Therefore, data from these stations are not presented.

A stage-discharge relation was established for H1 in 2009 and based upon 17 discharge measurements, figure 2.5. For further description of the Q/h-relation see Jensen and Rasch 2010.

By the end of 2011, 15 discharge measurements have been carried out while the outlet was affected by ice and/or snow. A few of the winter discharge measurements were carried out at water levels within the range of water levels seen during summer and fitted the Q/h-relation established in 2009. Therefore, the existing Q/h-relation has been upgraded for water levels at or below 98.735 m above a relative reference point based on 11 of the 15 winter discharge measurements, see figure 2.5. The threshold of 98.735 m is chosen as water levels beneath this value only occur during the winter.

Due to the establishment of a winter Q/h-relation, discharge data from previous years has been re-calculated and sent to the Nuuk Basic database at Department of Bioscience, Aarhus University.

River water discharge at H1

Figure 2.6 shows discharge at H1 from 2011. In 2011, the period with ice/snow free conditions at the outlet was from 21 May to 11 October.

The total discharge from H1 during the hydrological year from 1 October 2010 to 30 September 2011 was 34.3 million m³,

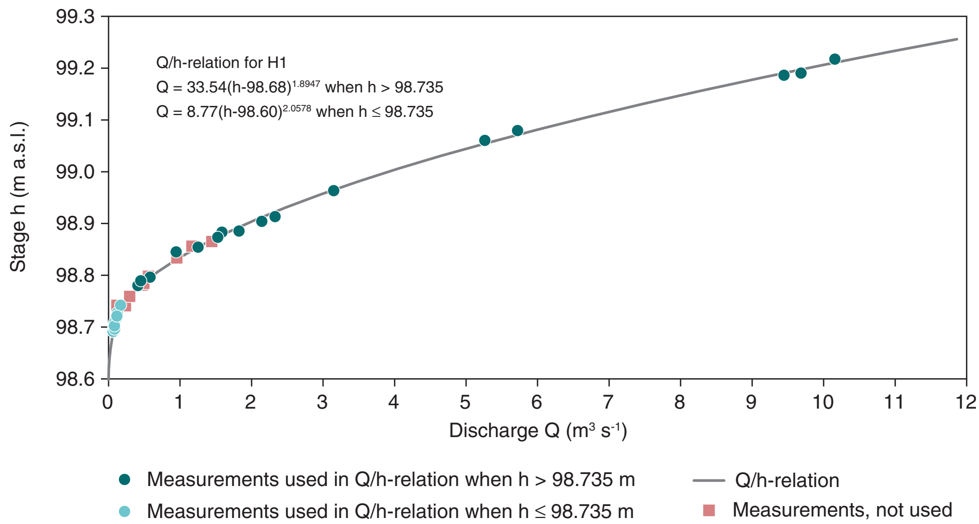


Figure 2.5 Stage-discharge relation at the hydrometric station H1. The coefficient of correlation (R2) is 0.998 for the curve above 98.735 m and 0.960 for the curve below 98.735 m.

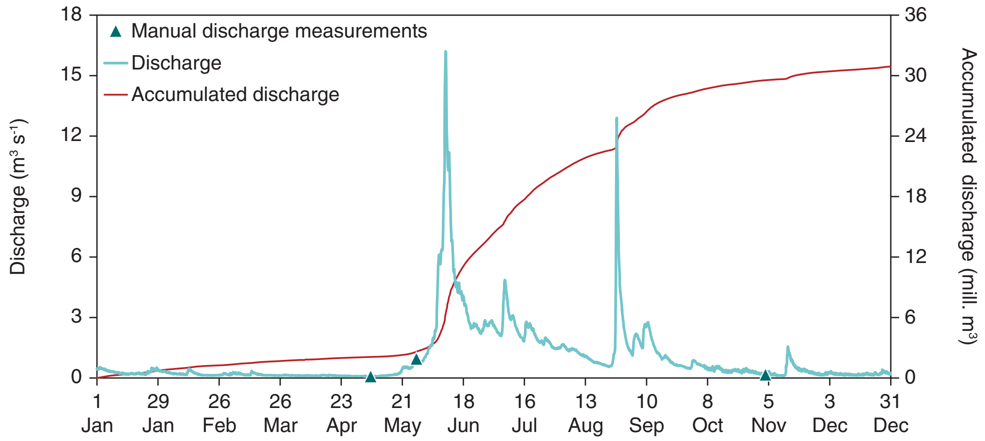


Figure 2.6 River water discharge at H1 during 2011.

Table 2.4 Total discharge for hydrological years 2007-2008 to 2010-2011.

Hydrological year	Total discharge (mill. m³)	Water loss (mm)
2007-2008	32.79	1058
2008-2009	40.83	1317
2009-2010	23.21	749
2010-2011	34.34	1108

which is 48 % more than in 2009/2010, see table 2.4. Total discharge from previous years is different than reported in earlier reports as the values have been re-calculated using the new winter Q/h-relation. The total discharge corresponds to a run-off of 1108 mm when assuming that the drainage basin covers 31 km^2. The majority of the snow pack melted and drained through the river during the first half of June, with discharge peaking 9 June at approximately 16 m^3 s^{-1}. This was the result of a combined effect of melting snow pack and rain. At the beginning of August, discharge had decreased to 1.5 m^3 s^{-1} and continued to decline slowly until a major rain event in the end of the month.

Water levels slowly began to rise 25 August and peaked in the morning of 27 August with an approximate discharge of 12.9 m^3 s^{-1}. When the rain stopped water levels quickly dropped again and had decreased to 1.5 m^3 s^{-1} by 1 September. By 11 October, discharge had decreased and remained stable around 0.5 m^3 s^{-1}. After 11 October when the river began to freeze, discharge dropped steadily to 0.13 m^3 s^{-1} by 10 November. A single thaw event during the autumn combined with rain increased discharge temporarily to 1.5 m^3 s^{-1} 13 November. By the end of the November and throughout December discharge remained stable at 0.2 m^3 s^{-1}.

3 NUUK BASIC

The GeoBasis Programme

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The GeoBasis programme provides long-term data of climatic, hydrological and physical landscape variables describing the environment in the Kobbefjord drainage basin close to Nuuk. GeoBasis was in 2011 operated by the Department of Geography and Geology, University of Copenhagen in collaboration with the Department of Bioscience, Aarhus University. In 2011, GeoBasis was funded by the Danish Ministry for Climate, Energy and Building as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. A part-time position is placed in Nuuk at Asiaq - Greenland Survey. The GeoBasis programme includes monitoring of the physical variables within snow and ice, soils, vegetation and carbon flux. The programme runs from 1 May to the end of October with some year round measurements from automated stations.

The 2011 season is the fourth full season for the GeoBasis programme. In 2007, the field programme was initiated during a three week intensive field campaign in August where most of the equipment was installed, although some installations had to be postponed until 2008. Methods and sampling procedures are described in detail in the manual 'GeoBasis - Guidelines and sampling procedures for the geographical monitoring programme of Nuuk Basic', which can be downloaded from www.nuuk-basic.dk

In 2011, GeoBasis installed two new energy balance stations (figure 3.1) in co-operation with an INTERACT project. One station is located at a new site over heath vegetation (figure 3.2), and has sensors measuring air temperature, relative humidity, air pressure, snow depth, summer precipitation, soil temperature (-70 cm, -50 cm, -20 cm, -10 cm and -2 cm), snow temperature (5 cm, 10 cm, 20 cm, 40 cm and 80 cm). In addition, it also measures NDVI, short and longwave radiation (incoming and outgoing), soil moisture (0-5 cm, 25 cm and 50 cm) and soil heat flux (4 cm). A sonic anemometer also measures wind speed and wind direction at high frequency (10 Hz).

A similar energy balance station (figure 3.1) was installed at the fen site, which measures air pressure, snow depth, summer precipitation, soil temperature (-70 cm, -50 cm, -20 cm, -10 cm and -2 cm) and snow temperature (5 cm, 10 cm, 20 cm, 40

Figure 3.1 Two new energy balance stations were installed during 2011. One at a new heath site (upper) and one at the fen site (lower).

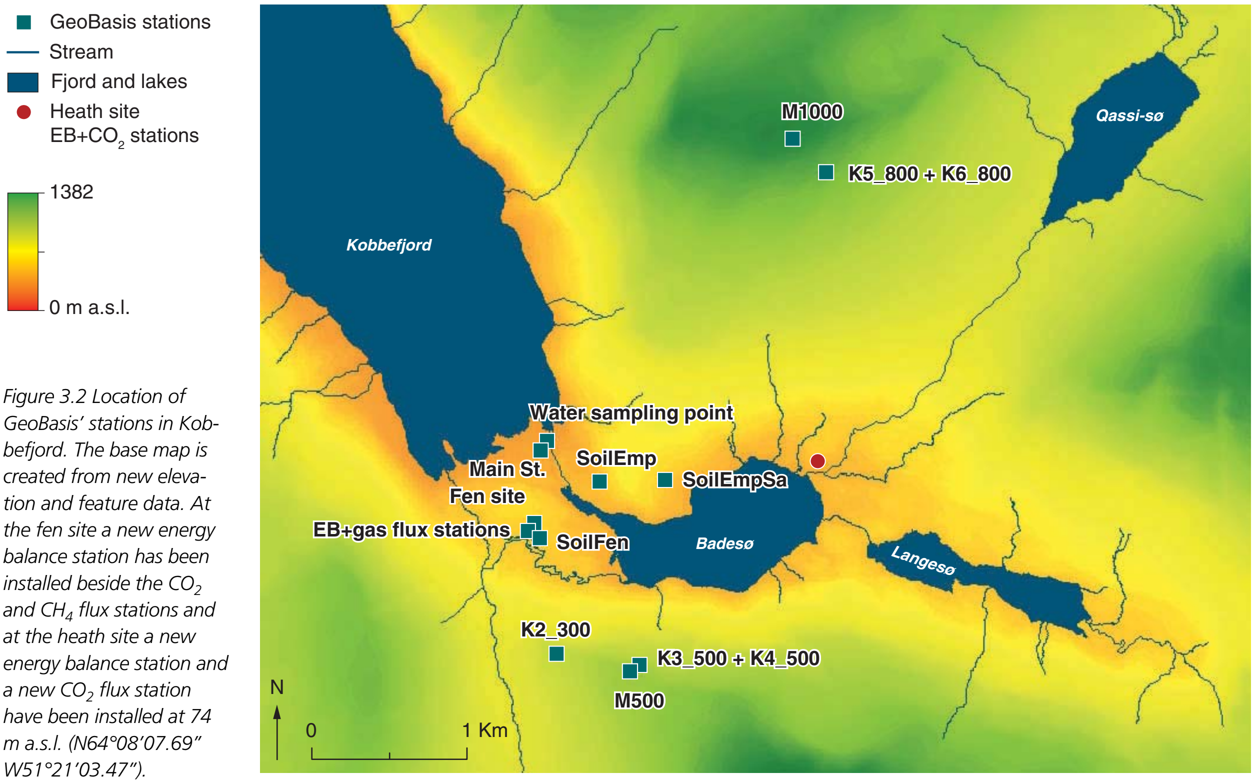
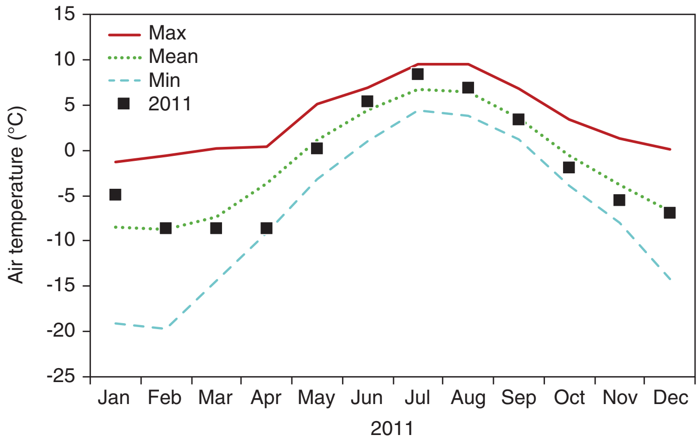


Figure 3.2 Location of GeoBasis' stations in Kobbefjord. The base map is created from new elevation and feature data. At the fen site a new energy balance station has been installed beside the CO_2 and CH_4 flux stations and at the heath site a new energy balance station and a new CO_2 flux station have been installed at 74 m a.s.l. (N64°08'07.69" W51°21'03.47").

cm and 80 cm). In addition, it also measures NDVI, short and longwave radiation (incoming and outgoing), soil moisture (0-5 cm) and water table elevation.

Data collected by the Danish Meteorological Institute (figure 3.3) shows that 2011 was colder than normal in Nuuk, the coldest since 1995. In 2011, the annual mean air temperature in Nuuk reached -1.6 °C, which is 0.3 °C colder than the average (Cappelen, 2012). Eight months were colder than normal, while only January, June, July and August were warmer than normal. Especially April was cold with an average monthly temperature of -8.6 °C, which makes it the second coldest record since the air temperature measurements were initiated in 1866 only exceeded by -9.1 °C registered in 1949.

Figure 3.3 The monthly minimum, mean and maximum air temperature for the period 1866-2011 measured at Nuuk (lines solid and dashed) and monthly mean air temperature for 2011 (points) (Cappelen, 2012).



3.1 Snow and ice

Snow cover extent

Three automatic cameras were installed in 2007 at 300 and 500 m a.s.l. to monitor the snow cover extent in the central parts of the Kobbefjord drainage basin. In September 2009, two snow monitoring cameras K5 and K6 were installed. Both cameras were installed at 770 m a.s.l. (N64°9'06.25" W51°20'46.47") see figure 3.2. K5 monitors Qassi-sø in the northern valley of the drainage basin while K6 is facing to the south monitoring the central parts of the drainage basin with Badesø and Langesø. A new camera was reinstalled at K1_300 overlooking the fen area (figure 3.4). This automatic camera takes photos three times daily from March through November, and once daily during the winter months.

One of the main advantages of camera-based snow monitoring is that it is relatively insensitive to cloud cover (in contrast to satellite-based techniques). Only low clouds and foggy conditions can make the image data unsuitable for mapping purposes. A new updated and more user friendly algorithm for snow cover

Figure 3.4 Reinstallation of snow camera K1_300 at 300 m a.s.l. (N64o7'26" W51o22'55"). The new camera has been raised approximately 2 m above the terrain to avoid snow formation in front of the camera.

monitoring has been developed in MatLab, so it is now possible, for each melting season, to construct snow cover depletion curves for user specified regions of interest (ROI) on the basis of image data obtained at daily frequency. Figure 3.5 show the results for three regions of interest (ROI) at respectively 200, 250 and 300 m a.s.l. seen from camera K2_300. The ROI at 300 m a.s.l. is facing to the west against the dominating wind direction, which causes a smaller snow accumulation and an earlier snow melt with 50 % of the snow cover melted 27 May (DOY 147) in 2011, which is the longest lasting snow cover registered during the previous four winter seasons. It was 25 days later than 2008 but only two days later than 2009. The depletion curves for ROI 300 in 2011 (figure 3.5) also indicates a snow melt period lasting for more than 30 days while the snow melt period in 2009 only lasted for 10 days. The ROI's at 200 and 250 m a.s.l. are facing to the north, which causes a leeward accumulation of snow and a later snow melt due to a shade effect from the surrounding mountains giving respectively 17 and 31 days delay in the snow melt for ROI 250 and ROI 200.

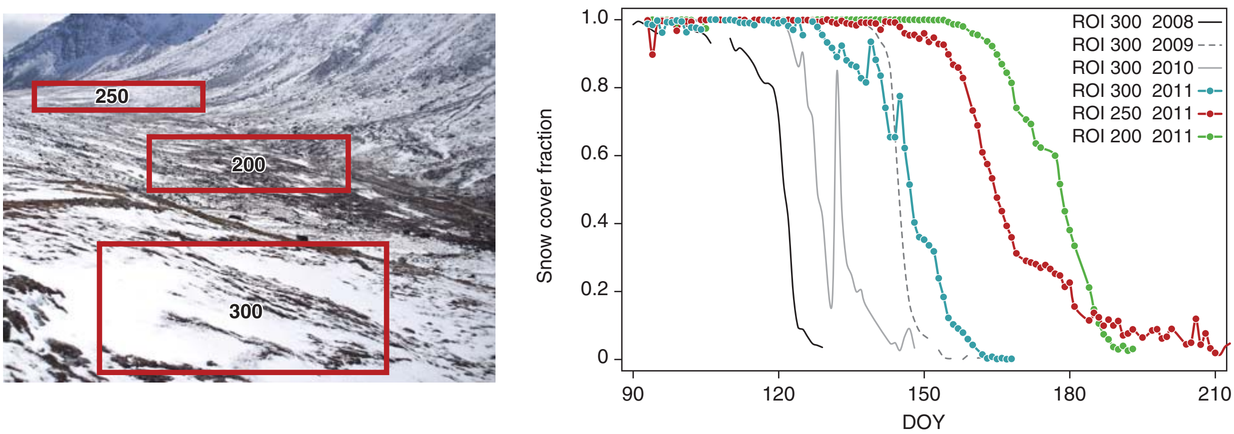


Figure 3.5 Snow cover depletion for three regions of interest 200, 250 and 300 m a.s.l. have been analysed using a new snow cover algorithm. The regions are specified on the image to the left, and the depletion curves for each region are shown in the diagram to the right. DOY= day of year. For ROI 300 the snow depletion for all four years is also shown and the image to the left show the area 14 May after a minor snowfall had occurred.

Table 3.1 Comparison of snow depth and densities (in brackets) at GeoBasis sites A-C, 2009-2011. No snow pit was dug at SoilEmpSa in 2010.

Snow survey dates	A) SoilFen Average depth (m) Density (kg m^{-3})	B) SoilEmp Sa Average depth (m) Density (kg m^{-3})	C) SoilEmp Average depth (m) Density (kg m^{-3})
April 15-16, 2009	0.91 (237)	0.90 (275)	1.02 (329)
April 15-16, 2010	0.20 (339)	0.19 (n.a.)	0.17 (366)
April 7-9, 2011	0.87 (364)	0.92 (297)	0.91 (383)

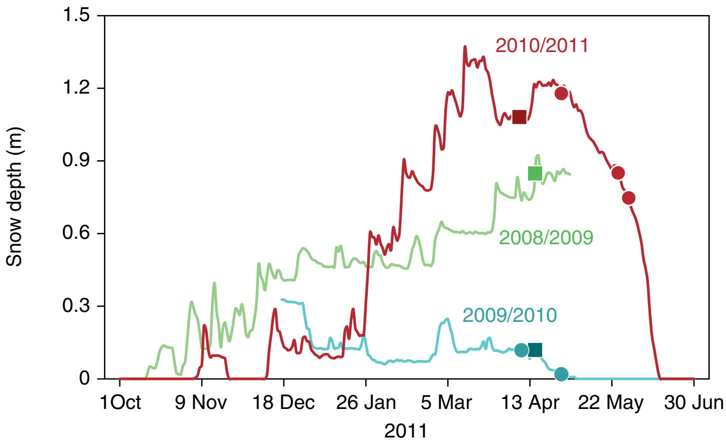


Figure 3.6 Snow depth measured at the ClimateBasis station and placement of snow surveys, 2009-2011. Squares represent the main survey for the year and the small dots represent additional snow surveys.

Snow cover

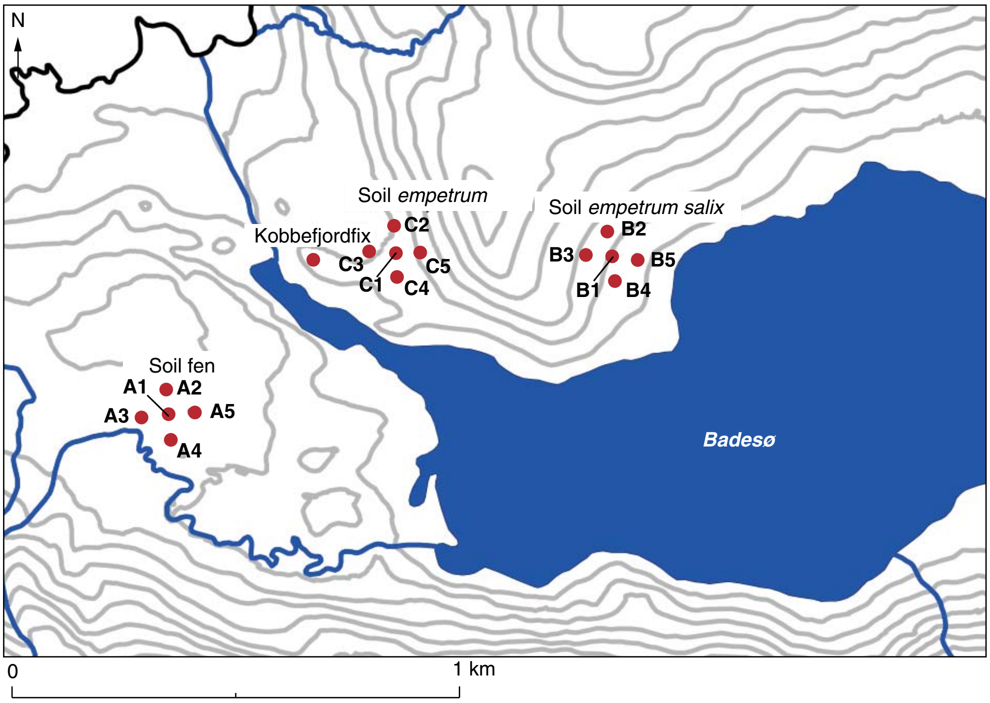
To support studies under the Nuuk Basic monitoring programme, a snow cover survey using ground penetrating radar (GPR) and manual stake measurements was carried out in the main parts of the Kobbefjord drainage basin 7-9 April 2011. Additional surveys were carried out 28 April, 25 May and 30 May 2011, involving only manual measurements of snow depth and densities. A comparison of average snow depth for the three GeoBasis sites can be seen in table 3.1. Both 2009 and 2011 had snow depth above 90 cm, but the densities of the snow pack in 2011 was 340 kg m^{-3} compared to only 280 kg m^{-3} in 2009 giving a significant higher snow water equivalent of 313 mm in 2011 compared to 264 mm in 2009.

Even though the snow survey is carried out at nearly the same time every year, snow depth has large variations from year to year and the maximum snow cover date is highly variable from year to year, see figure 3.6. Compared to previous years, the winter 2010/2011 started with an exceptional low amount of snow with a maximum snow depth of only 25 cm at the meteorological station. Only after 26 January did the snow depth exceed 30 cm and during the next two months the snow depth increased steadily until it reached 137 cm 13 March. This caused the winter 2010/2011 to be the snowiest winter and having the largest amount of snow and the longest duration of snow, since continuous measurements of snow depth started in 2008. The snow surveys in both 2009 and 2010 took place close to the date of maximum snow cover. In 2011, a sudden thaw event in mid-March drastically reduced snow depths, and thereby the main snow survey did not occur at the maximum snow cover. However, an additional survey in late April 2011 allowed for measurements with greater snow cover.

Table 3.2 describes snow depths and densities at the three GeoBasis soil microclimate stations SoilFen, SoilEmp and SoilEmpSa using ground penetrating radar (GPR) and manual stake measurements (figure 3.7). The snow survey strategy used in the Kobbefjord area is outlined in Hansen et al. 2010. In order to document the properties of the snowpack, snow pits were dug at SoilFen in point A1, at SoilEmpSa in point B1 and at SoilEmp in point C1 (figure 3.7). The examination of the snowpack included temperature profiling, density measurements and texture description. Table 3.2 summarizes the snow depth, density and temperature from the three stations. The texture of the

Table 3.2 Snow pit depth, average density, snow depth, standard deviation of the snow depth, average snow temperature and average water equivalent at the three soil stations (SoilFen, SoilEmp and SoilEmpSa) measured 7-9 April 2011.

Site	Snow pit depth (cm)	Avg. density (kg m^{-3})	Snow depth (min-avg.-max) (cm)	Standard dev. of snow depth (cm)	Avg. snow temperature (°C)	Avg. water eq. (mm)
SoilFen (A1)	84	364	58 - 87 - 130	10	-5.0	306
SoilEmp Sa (B1)	52	298	73 - 92 - 123	15	-3.4	155
SoilEmp (C1)	93	383	63 - 91 -105	11	-4.1	356



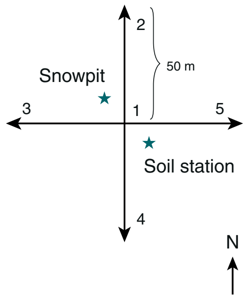


Figure 3.7 Map showing the three snow survey sites. The figure on the right outlines the strategy at each site.

snow profile at both SoilFen and SoilEmp are characterized as homogenous coarse grained snow with densities between 364-383 kg m^{-3}, while at SoilEmpSa both snow depth (52 cm) and density (298 kg m^{-3}) are significantly lower.

When comparing the snow cover survey 2011 with previous years, the snow depth on the three locations is similar to 2009, but much higher compared to 2010, see table 3.1.

Ice cover

The ice cover of the lakes in the Kobbefjord drainage basin was generally formed later during the winter 2010/2011 than in previous winters (table 3.3). The break-up of the ice covers on the lakes was approximately one to two weeks later than in the previous years. Unfortunately, an unexpected breakdown of the camera covering Kobbefjord occurred in the period 27 September 2010 to 15 May 2011. Ice cover was still dominating the inner parts of Kobbefjord until the end of May. As usual, an ice cover was formed two to three weeks earlier on Qassi-sø (250 m a.s.l.) than on Badesø (30 m a.s.l.), and as usual the ice cover on Qassi-sø broke up ten days later than the ice cover on Badesø. The difference in the period of ice cover is due to the difference in elevation of the two lakes.

Micrometeorology

Table 3.4 reports the monthly mean air temperature, relative humidity, surface temperature and soil temperature measured at SoilFen 2007-2011. 2010 was

*Table 3.3 Visually estimated dates for perennial formation (50%) of ice cover and date for break-up of ice cover on selected lakes within the Kobbefjord drainage basin and on Kobbefjord from 2007 to 2011. Dates are reported for perennial formation of ice cover in the fall and for the break-up of ice cover in the spring. Badesø is the main lake in the area, Langesø is the long lake in the valley behind and to the east of Badesø and Qassi-sø is the lake at 250 m a.s.l. in the northern valley of the drainage basin. No data indicates failure of the camera system and *indicates that it was not possible to estimate an exact date due to low cloud cover in the area.*

Year	Badesø		Langesø		Qassi-sø		Kobbefjord	
	Break-up	Formation	Break-up	Formation	Break-up	Formation	Break-up	Formation
2007		23 Oct		22 Oct		22 Oct	12 Feb*	27 Dec
2008	2 Jun	5 Nov	13 May	5 Nov	9 June	4 Nov		
2009	13 Jun	1 Nov	11 Jun	no data	22 Jun	10 Oct	4 Jun	12 Feb
2010	14 May	22 Nov	no data	no data	24 May	6-11 Nov	2 Jun	23 Nov
2011	18 Jun		no data		28 Jun		23 May	

Table 3.4 Air temperature, relative humidity, surface temperature and soil temperature at five depths (1 cm, 10 cm, 30 cm, 50 cm and 75 cm) from the SoilFen station in the fen area, August 2007 to December 2011.

Month-year	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface temp. 0 m (°C)	Soil temp. -1 cm (°C)	Soil temp. -10 cm (°C)	Soil temp. -30 cm (°C)	Soil temp. -50 cm (°C)	Soil temp. -75 cm (°C)
2007								
August	7.6	84.1	7.6	9.0	9.8	10.1	8.6	7.4
September	3.8	70.1	1.9	3.4	4.3	5.3	5.9	5.8
October	–0.5	64.6	–4.8	–0.6	0.2	1.1	2.3	2.8
November	–3.5	74.2	–7.1	–0.3	–0.2	0.4	1.2	1.7
December	–8.9	71.8	–13.1	–0.2	–0.2	3.0	0.9	1.3
2008								
January	–12.1	73.2	–16.0	–0.3	–0.1	0.3	0.8	1.2
February	–13.5	73.1	–15.7	–0.3	–0.1	0.2	0.7	1.0
March	–8.8	75.0	–11.5	–0.3	–0.1	0.2	0.7	1.0
April	–	–	–	–	–	–	–	–
May	–	–	–	–	–	–	–	–
June	–	–	–	–	–	–	–	–
July	–	–	–	–	–	–	–	–
August	7.4	76.6	7.6	9.3	9.2	8.6	8.4	7.6
September	4.1	77.8	3.9	4.7	5.2	5.9	6.0	6.0
October	–0.1	69.3	–2.4	0.1	0.9	2.6	2.9	3.5
November	–1.9	79.8	–4.4	–0.1	0.2	1.3	1.6	2.1
December	–8.1	71.8	–11.9	–0.2	0.1	1.0	1.2	1.6
2009								
January	–5.5	67.6	–10.1	–0.2	0.1	0.9	1.1	1.4
February	–6.2	69.3	–10.7	–0.3	0.0	0.7	0.9	1.2
March	–12.0	73.7	–16.8	–0.5	–0.1	0.6	0.7	1.1
April	–3.4	78.8	–6.7	–0.2	–0.1	0.5	0.7	1.0
May	0.3	71.7	–3.3	0.0	0.0	0.5	0.7	1.0
June	6.3	76.6	7.2	7.0	4.7	2.6	2.3	2.0
July	10.2	72.1	13.1	14.3	12.7	8.7	7.8	6.3
August	8.7	77.2	10.1	10.8	10.6	9.1	8.6	7.7
September	3.5	73.9	2.9	3.9	4.7	5.8	5.9	5.9
October	–0.7	69.2	–3.2	–0.2	0.5	2.2	2.5	3.1
November	–8.1	74.2	–13.6	–0.3	0.0	1.1	1.4	1.9
December	–2.9	61.0	–8.7	–0.6	–0.2	0.8	1.0	1.5
2010								
January	–3.8	71.1	–7.0	–1.9	–1.0	0.5	0.7	1.1
February	–1.6	67.7	–5.4	–3.2	–2.3	0.1	0.3	0.8
March	–4.5	69.8	–7.9	–2.2	–1.8	–0.2	0.1	0.5
April	–0.1	74.1	–3.0	–0.5	–0.5	–0.1	0.1	0.4
May	6.9	68.8	6.9	6.2	2.3	0.0	0.1	0.4
June	8.6	73.6	10.7	10.9	7.8	1.0	0.8	0.7
July	10.2	78.2	12.6	13.8	12.1	7.9	6.9	5.5
August	11.3	79.8	11.7	12.6	11.9	9.7	9.0	7.9
September	7.4	73.4	6.5	7.3	7.7	7.7	7.6	7.2
October	2.8	71.1	0.7	1.5	2.4	3.9	4.2	4.6
November	1.0	69.7	–2.4	–0.4	0.1	1.6	2.0	2.5
December	0.3	75.5	–2.5	–0.1	0.0	1.0	1.3	1.8
2011								
January	–5.6	70.6	–8.7	–0.7	–0.2	0.7	1.0	1.4
February	–9.1	73.2	–12.0	–0.4	–0.2	0.5	0.7	1.1
March	–9.5	73.6	–11.6	–0.2	–0.2	0.5	0.7	1.0
April	–9.7	69.5	–12.6	0.0	0.0	0.5	0.7	1.0
May	0.5	71.5	–1.2	0.0	0.1	0.5	0.7	1.0
June	6.1	77.0	5.4	4.8	2.5	1.2	1.1	1.2
July	9.6	78.5	11.2	12.4	11.0	7.4	6.6	5.3
August	8.2	81.3	9.4	11.0	10.5	8.6	8.1	7.1
September	3.5	77.8	3.2	4.1	4.8	5.9	6.0	5.9
October	–2.4	70.5	–4.3	0.0	0.7	2.3	2.6	3.1
November	–6.2	65.8	–8.7	–2.3	–1.1	0.8	1.1	1.7
December	–7.6	74.3	–9.5	–0.7	–0.5	0.2	0.5	1.0

unusually warm and had the maximum mean air temperature for all months measured at SoilFen. In the first months of 2011, the mean air temperature was in the average range. April 2011 was a cold month compared to previous years; the rest of 2011 had the lowest or close to the lowest measured mean air temperature. Figure 3.8 shows a comparison between the monthly mean air temperatures in 2011 and the maximum and the minimum monthly mean air temperatures from SoilFen in 2007-2011. These measurements are in line with the air temperature measured in Nuuk located 30 km away.

For the monitoring period 2007-2011, the minimum monthly mean air temperature was -13.5 °C measured at SoilFen in February 2008, and the maximum monthly mean air temperature was 11.3 °C measured in August 2010.

The micrometeorological stations M500 and M1000 measure air temperature, relative humidity, surface temperature and shortwave irradiance, see tables 3.5 and 3.6. M500 is placed approximately 500 m a.s.l. south of Badesø and M1000 is placed approximately 1000 m a.s.l. north of Badesø. The low monthly mean air temperature at SoilFen in April 2011 is also seen in the data from M500 and M1000. In 2008-2010, the mean air temperature in April at the M500 station was between -5.3 °C and -2.4 °C, in 2011 it was -12.6 °C. The humidity measured at the M500 station is generally high compared to previous years and the monthly mean incoming shortwave irradiance for July is lower than previous years.

3.2 Soil

Physical soil properties

The results of selected parameters for the soil stations SoilFen, SoilEmp and SoilEmpSa are presented in tables 3.4, 3.7 and 3.8. The difference in soil properties between the three locations, which were detected in previews years are also seen in the data collected in 2011. Those being higher winter soil temperatures at SoilFen than at SoilEmp and SoilEmpSa. The temperature in 30 cm depth is at SoilFen less affected by fluctuations in surface temperature than at SoilEmp and SoilEmpSa where the soil is well-drained. The results of the measured soil water content show markedly lower values for the well-drained soil at SoilEmp than at SoilEmpSa. The monthly mean soil moisture for the field season was 12 % at SoilEmp and 36 % at SoilEmpSa. At the three soil stations, the soil temperatures are higher in January-April 2011, especially compared to 2010. 2010 was a very warm year, but the lack of snow led to less insulation and lower soil temperatures. During winter 2011, the snow layer was thick and isolated the soil from the air temperature. During summer 2011, the soils had lower temperatures and were more moist than normal.

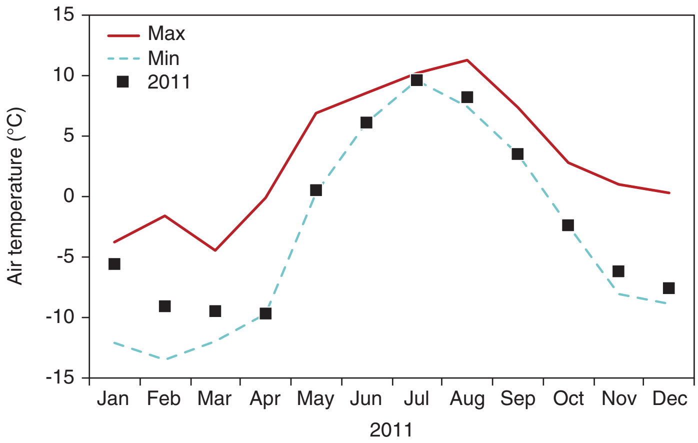


Figure 3.8 Monthly mean air temperatures in 2011 (squares), and maximum (dashed line) and minimum (solid line) monthly mean air temperatures from 2007-2011 at the SoilFen station 2.5 meter above ground.

Soil water

Sixty soil water samples were collected from the soil water stations at SoilEmp and SoilFen during the period 15 June – 3 October 2011. At the research cabin in Kobbefjord, measurements of pH, temperature and conductivity were carried out on the samples. In August 2011, laboratory equipment was installed in the research cabin, which enabled analyses of soil water alkalinity. Due to delay in the analyses from the laboratory, the results of soil water chemistry will be reported in the 2012 annual report.

River water

In 2011, forty water samples were collected from mid-May to mid-October, the field season being one month shorter than previous years due to a very late snow- and ice melt. *In situ* measurements of river water temperature, conductivity and pH were carried out along with the water sampling. The measured values are presented in figure 3.9. The minimum river water temperature varied between 0.4-0.5 °C from mid-May to mid-June, which was 1.0 °C lower than in 2010, and the water temperature peaked with a maximum

Table 3.5 Air temperature, relative humidity, surface temperature and shortwave irradiance measured at the M500 station from January 2008 to August 2011. (Data from September to December are not yet retrieved).

Month-year	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface temp. 0 m (°C)	Shortwave irradiance 2.5 m (W m^{-2})
2008				
January	–14.3	78.5	–16.3	6.7
February	–15.6	78.1	–17.3	30.3
March	–10.7	83.5	–12.3	77.2
April	–2.4	67.2	–4.6	172.5
May	2.4	73.2	3.5	237.0
June	5.9	72.1	8.7	295.1
July	8.9	64.3	10.5	253.7
August	5.4	80.1	6.3	157.7
September	0.1	90.0	–0.7	74.0
October	–3.2	77.6	–6.2	38.2
November	–5.0	91.4	–6.2	8.5
December	–10.8	82.2	–13.0	3.3
2009				
January	–7.7	72.0	–11.4	6.9
February	–8.1	69.7	–11.8	30.1
March	–13.1	76.5	–16.1	95.1
April	–5.3	83.9	–7.6	166.9
May	–2.5	79.9	–3.1	254.2
June	3.4	83.2	5.5	220.8
July	8.8	67.8	11.0	287.7
August	7.1	74.2	7.7	188.5
September	–0.2	84.4	–1.2	82.8
October	–3.6	74.9	–6.4	44.6
November	–9.2	75.1	–12.2	11.8
December	–3.8	57.5	–9.3	3.3
2010				
January	–5.5	73.8	–9.1	5.9
February	–2.7	65.4	–7.5	29.6
March	–6.7	73.1	–9.6	80.4
April	–2.9	79.9	–5.4	170.4
May	4.6	71.3	3.8	205.6
June	5.7	79.9	7.9	211.4
July	8.5	76.3	11.2	217.8
August	9.0	81.3	8.8	132.6
September	5.0	73.5	3.0	89.1
October	0.5	73.1	–2.8	35.8
November	–1.3	73.1	–4.6	8.8
December	–1.7	78.7	–4.3	2.3
2011				
January	–7.6	73.8	–11.0	6.8
February	–11.5	78.1	–13.9	27.8
March	–11.7	80.7	–13.9	76.8
April	–12.6	82.3	–14.5	187.5
May	–3.0	81.0	–3.5	239.2
June	4.6	77.9	7.2	238.7
July	7.6	79.2	8.6	165.8
August	6.8	77.0	7.3	149.8

Table 3.6 Air temperature, relative humidity, surface temperature and shortwave irradiance measured at the M1000 station from October 2009 to November 2011. (Data from December are not yet retrieved).

Month-year	Air temp. 2.5 m (°C)	Rel. hum. 2.5 m (%)	Surface temp. 0 m (°C)	Shortwave irradiance 2.5 m (W m⁻²)
2009				
October	–6.2	90.1	–6.8	25.5
November	–10.4	67.4	–13.2	15.8
December	–5.2	55.4	–10.2	4.5
2010				
January	–6.9	71.2	–9.8	7.1
February	–4.3	62.9	–8.3	32.8
March	–8.7	73.1	–10.0	88.4
April	–7	90.9	–7.9	135.5
May	–	–	–	–
June	3.2	94.8	9.3	173.1
July	7.1	75.7	11.8	230.3
August	7.3	82.8	8.7	138
September	2.8	75.2	2.8	103.8
October	–1.8	75.2	–3.5	45.2
November	–3.8	79.3	–5.5	9
December	–3.6	81.5	–5.4	2.2
2011				
January	–9.7	72.7	–11.5	8.2
February	–13.7	76.3	–14.3	29.6
March	–14.2	83.9	–13.6	80.3
April	–15	77.9	–14.7	191.9
May	–5.2	80.0	–3.2	245.9
June	3.8	73.3	7.6	256.9
July	5.6	81.9	7.8	177.3
August	5.2	76.3	6.7	157.1
September	–1.6	81.0	–2.4	97.9
October	–6.8	71.4	–8.7	50.1
November	–11.2	72.6	–13.4	15.8

temperature of 13.3 °C in mid-August, which was 2.5 °C lower than previous years. The conductivity shows a significant decrease during the snow melting period (May-June) to a level of 18 +/- 1.5 µSc m^{-1}. From the beginning of July and through the rest of the field season, the conductivity shows no significant trend. pH shows a constant level of 6.8 +/- 0.4 from May to October 2011.

3.3 Vegetation

Vegetation in the Kobbefjord area is monitored by the BioBasis and GeoBasis programmes. While BioBasis monitors individual plants and plant phenology using plot scale sites and transects, the GeoBasis programme monitors the phenology of the vegetation communities from satellite.

Figure 3.9 Water temperature, conductivity and pH measured in the river Kobbefjord at the water sampling point in 2011.

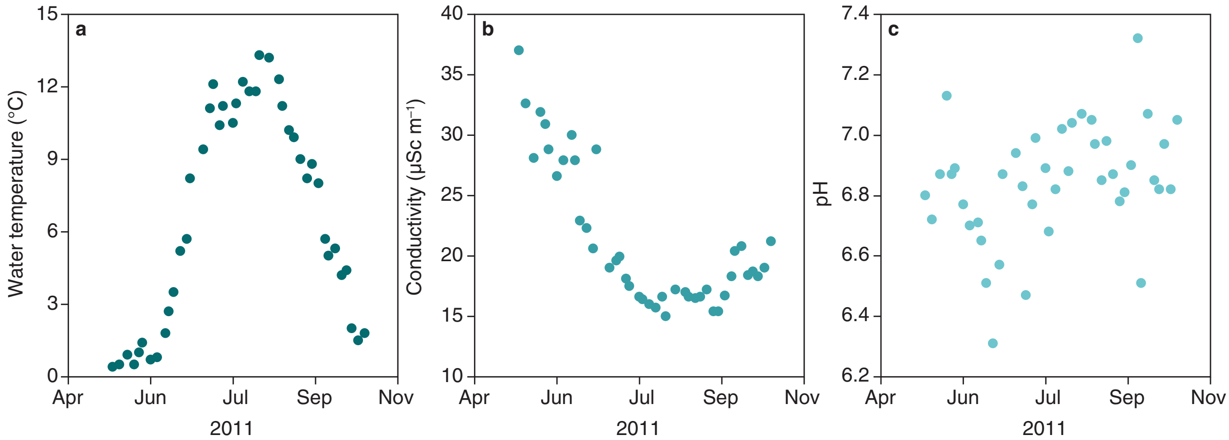


Table 3.7 Soil temperature and soil moisture at four depths measured at SoilEmp from January 2009 to December 2011.

Month-year	Soil temp. −1 cm (°C)	Soil temp. −5 cm (°C)	Soil temp. −10 cm (°C)	Soil temp. −30 cm (°C)	Soil moist. −5 cm (%)	Soil moist. −10 cm (%)	Soil moist. −30 cm (%)	Soil moist. −50 cm (%)
2009								
January	−0.9	−0.7	−0.5	−0.1	2	12	4	3
February	−1.3	−1.1	−1.0	−0.5	1	9	2	2
March	−2.5	−2.3	−2.2	−1.7	1	7	1	1
April	−1.4	−1.4	−1.3	−1.1	1	8	1	1
May	0.0	0.0	0.0	0.0	14	21	15	14
June	7.4	7.0	6.7	5.6	32	45	40	41
July	12.4	11.8	11.5	10.4	9	35	14	12
August	10.3	10.1	10.0	9.5	3	17	4	3
September	4.0	4.4	4.6	5.0	6	26	6	5
October	−0.5	−0.3	−0.1	0.4	12	25	17	15
November	−1.5	−1.3	−1.1	−0.4	2	13	3	3
December	−1.9	−1.8	−1.7	−1.2	1	10	2	2
2010								
January	−5.2	−5.1	−4.9	−3.9	1	8	2	2
February	−5.3	−5.1	−5.0	−4.1	1	8	1	2
March	−4.5	−4.4	−4.4	−3.9	1	8	1	2
April	−0.6	−0.8	−0.8	−0.8	6	16	10	8
May	6.4	5.6	5.1	3.8	19	42	34	31
June	10.1	9.4	9.0	7.7	5	35	8	5
July	12.4	11.8	11.4	10.4	4	28	5	4
August	11.6	11.3	11.2	10.6	11	37	15	15
September	7.0	7.3	7.4	7.6	9	38	14	11
October	1.6	2.1	2.4	3.0	6.6	36.4	6.6	4.7
November	−0.7	−0.5	−0.4	0.2	4.6	16.2	6.7	4.9
December	−0.2	−0.2	−0.1	0.2	13.6	35.6	25.7	24.5
2011								
January	−1.7	−1.5	−1.2	−0.4	3.2	13.6	5.2	4.4
February	−1.3	−1.1	−1.0	−0.6	2.4	9.9	3.6	3.5
March	−1.3	−1.2	−1.1	−0.8	2.4	9.7	3.4	3.4
April	−0.7	−0.6	−0.5	−0.3	2.5	10.0	3.4	3.4
May	0.0	0.0	0.1	0.1	11.1	17.9	14.1	15.5
June	5.3	4.7	4.3	3.2	27.1	38.6	26.0	31.8
July	10.9	10.5	10.2	9.1	7.9	37.5	8.9	6.2
August	10.1	10.0	9.8	9.3	7.3	36.3	8.3	6.7
September	3.8	4.2	4.4	4.9	12.6	39.8	22.8	20.0
October	−0.7	−0.3	−0.1	0.7	6.4	25.3	7.7	6.0
November	−4.7	−4.4	−4.0	−2.5	2.8	8.4	3.6	4.9
December	−2.6	−2.5	−2.4	−2.1	2.9	8.5	3.5	4.1

Satellite imagery

Unlike the years 2008 to 2010, it was not possible to acquire QuickBird or World-View image data due to cloudy conditions in the requested period. Instead, Landsat data based on the enhanced thematic mapper 7 sensor (ETM7) was ordered despite its lower spatial resolution at 30×30 m. The most cloud free conditions were met 14 July 2011 (figure 3.10). The Landsat satellite has experienced an instrument malfunction since mid-2003, which resulted in a scan line error (seen as black (no-data) lines across the images), and therefore data from the open mixed heath plot was not available. A Landsat scene from 30 July 2011 was used to compensate for this.

Both scenes were geometrically/geodetically corrected products (L1T) when acquired, and were subsequently corrected atmospherically with dark object subtraction (regions of interest over the deep fjords constituted the dark areas). The Normalized Difference Vegetation Index (NDVI) was then computed from the corrected bands.

Table 3.8 Soil temperature and soil moisture at four depths measured at SoilEmpSa from January 2009 to December 2011.

Month-year	Soil temp. –1 cm (°C)	Soil temp. –5 cm (°C)	Soil temp. –10 cm (°C)	Soil temp. –30 cm (°C)	Soil moist. –5 cm (%)	Soil moist. –10 cm (%)	Soil moist. –30 cm (%)	Soil moist. –50 cm (%)
2009								
January	–	–	–0.3	0.2	37	27	41	38
February	–	–	–1.1	–0.3	15	13	33	32
March	–	–	–1.4	–0.7	13	12	12	25
April	–	–	–0.4	–0.2	15	13	13	14
May	–	–	0.0	0.0	30	21	17	16
June	–	–	4.1	3.5	59	52	38	35
July	–	–	11.0	9.5	51	42	45	45
August	–	–	10.2	9.1	40	30	38	33
September	–	5.3	5.0	5.5	–	32	38	33
October	0.4	0.9	0.8	1.0	60	53	44	48
November	–0.4	0.2	0.0	0.3	52	37	41	42
December	–0.7	–0.2	–0.4	–0.1	28	21	38	35
2010								
January	–1.7	–1.0	–1.4	–0.5	23	14	19	34
February	–2.6	–1.8	–2.2	–1.3	21	13	12	22
March	–1.9	–1.7	–1.8	–1.4	20	12	11	12
April	–0.2	–0.3	–0.3	–0.3	26	15	12	13
May	3.1	1.3	1.7	1.0	59	47	26	17
June	8.3	6.0	6.8	5.5	60	46	47	46
July	11.4	9.7	10.6	9.2	56	32	42	38
August	11.0	10.2	10.4	10.1	59	49	44	45
September	7.6	7.7	7.6	7.7	60	49	46	49
October	2.7	3.7	3.1	4.0	58.1	36.0	44.2	43.0
November	–0.2	0.6	0.2	0.9	57.0	36.3	44.2	40.7
December	0.4	0.7	0.6	0.7	60.2	54.4	46.3	46.6
2011								
January	–1.1	–0.2	–0.5	0.0	32.7	25.9	44.5	43.3
February	–0.6	–0.3	–0.5	–0.2	23.5	14.8	41.8	37.0
March	–0.6	–0.4	–0.5	–0.3	23.6	14.5	25.0	33.5
April	–0.7	–0.5	–0.6	–0.4	23.8	14.4	19.3	31.5
May	0.1	0.1	0.1	0.2	30.5	21.5	20.0	32.7
June	3.9	3.2	3.4	3.0	53.4	47.0	35.9	45.1
July	10.3	9.0	9.2	8.9	60.0	51.9	47.4	49.9
August	10.2	9.3	9.6	9.1	58.0	39.9	45.0	44.2
September	4.7	5.1	5.0	5.2	60.1	53.3	46.9	49.4
October	0.2	1.0	0.6	1.3	52.0	40.2	45.2	45.5
November	–1.9	–0.8	–1.4	–0.3	21.9	15.1	40.5	39.4
December	–0.9	–0.7	–0.8	–0.5	21.3	13.5	15.7	35.1

As part of an INTERACT project, a new climate station was installed during the 2011 field season at a heath site north of Badesøen. Hence, a new region has been added to the satellite-based NDVI measurements, as seen in figure 3.11.

NDVI values were generally lower than previous years, partly due to outbreaks of especially *Eurois occulta* larvae, which damaged the vegetation.

3.4 Carbon gas fluxes

Carbon gas fluxes are monitored on plot and landscape scale in a fen in the Kobbefjord area using two techniques:

- Automatic chamber measurements of CH_4 and CO_2 exchange on plot scale
- Eddy covariance measurements of CO_2 and H_2O exchange on landscape scale

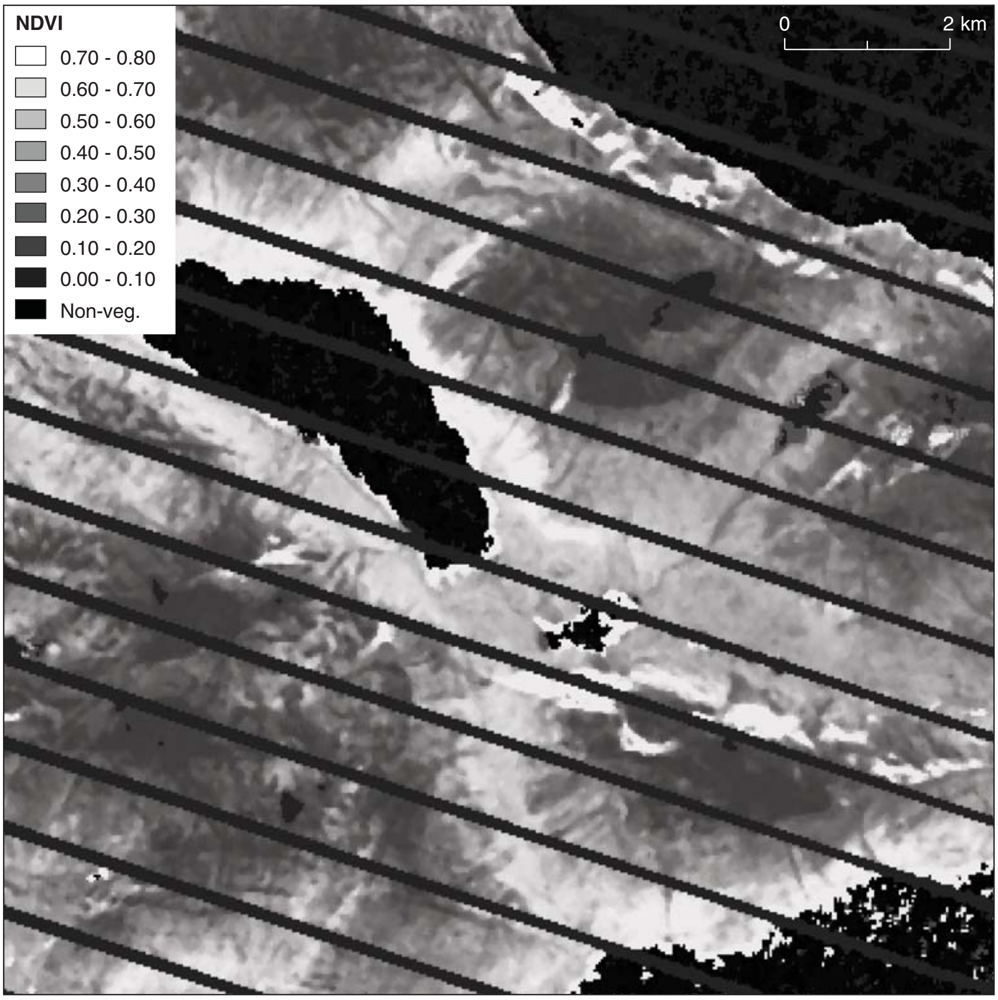


Figure 3.10 Normalised Difference Vegetation Index (NDVI) based on Landsat data based on the enhanced thematic mapper 7 (ETM7) imagery from 14 and 30 July 2011. Data are dark subtracted as atmospheric correction and lack the topographic correction.

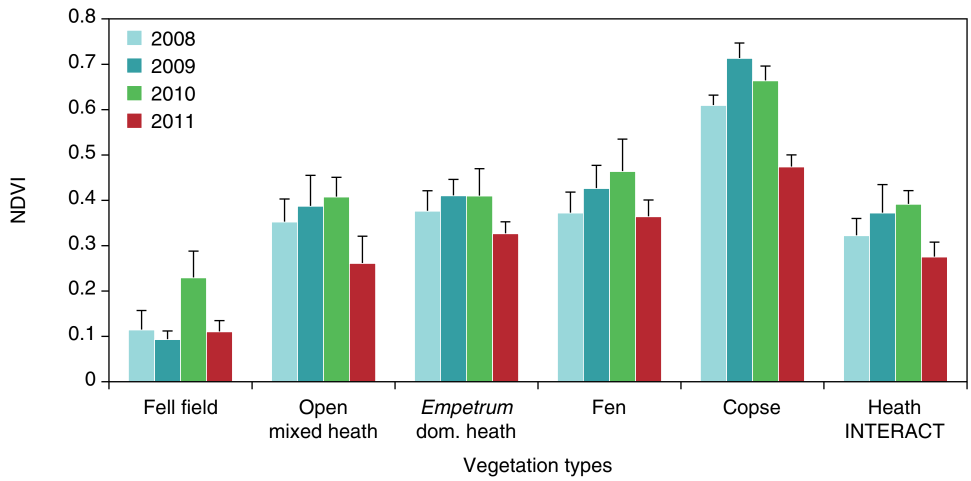


Figure 3.11 NDVI from 17 July 2008 and 2009, 10 July 2010, and 14 and 30 July 2011 for the five different vegetation types. Notice that changes between greenness are due not only to phenology differences between years but also seasonal phenology as the image is acquired approximately two weeks before the maximum greenness and on different dates.

Automatic chamber measurements

An automatic chamber system consisting of six flux chambers for monitoring of exchange of CH_4 and CO_2 was installed in the fen in August 2007 (Tamstorf et al. 2008). In 2011, the system was setup on site in late June; however, due to several technical and instrumental problems the system was not fully operational until 26 July. Measurements were terminated 18 October. Gaps in data originated from maintenance, calibration and malfunction due to various errors such as fox bites and instrument failures.

The spatial and temporal variation in CH_4 emissions (figure 3.12) is primarily related to temperature, water table depth and net primary production. The fen in the Kobbefjord area is a source of CH_4 due to the permanently wet conditions that pro-

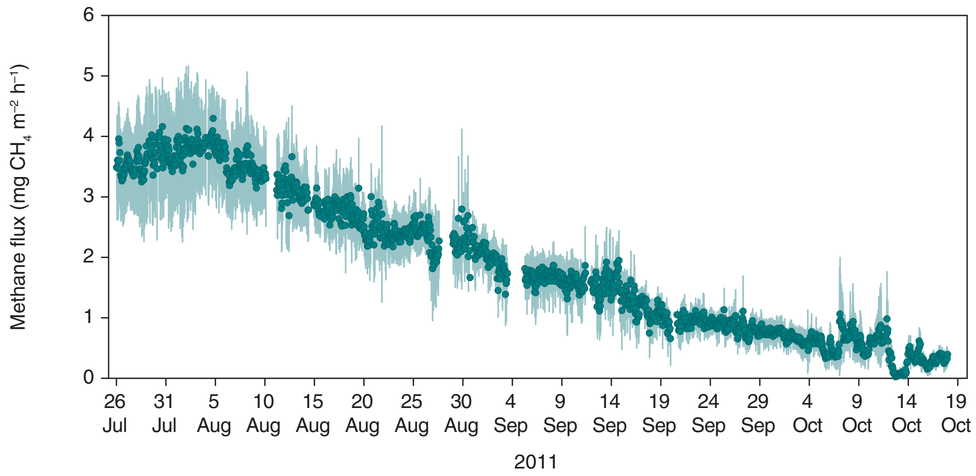


Figure 3.12 Methane (CH_4) emissions from the fen during 2011.

mote anaerobic decomposition, by which CH_4 is an end product.

Due to the late onset of CH_4 flux measurements in 2011, the CH_4 flux dynamics during the early growing season cannot be described. There was a peak in CH_4 emission in early August, amounting to approximately 4 mg CH_4 m^{-2} h^{-1}. The peak level is comparable to the previous years 2008 and 2010, but lower than in 2009. The peak occurred later compared with previous years, most likely due to the late snow melt in 2011 (see next section). After the peak, emissions decreased steadily and reached below 1 mg CH_4 m^{-2} h^{-1} in October. Overall, the observed temporal CH_4 flux pattern of the Kobbefjord fen displays low shoulder season emissions with a dome-shaped peak during the growing season.

Eddy covariance measurements

In order to describe the inter-annual variation of the seasonal CO_2 balance, the soil-atmosphere CO_2 exchange in a fen has been monitored using the eddy covariance technique since 2008. The eddy covariance system consists of a 3D sonic anemometer and closed path infrared CO_2 and H_2O gas analyzer (Tamstorf et al. 2009). Raw data from the eddy covariance system was calculated using the software package EdiRe (Robert Clement, University of Edinburgh). For more details on the flux calculation procedures see Hansen et al. 2011.

The temporal variation in mean daily net ecosystem exchange of CO_2 (NEE) and air temperature during 2011 for the fen site is shown in figure 3.13 and various variables summarized in table 3.9. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants, plant respiration and microbial decomposition. The CO_2 exchange is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), along with amount of biomass and soil moisture content. The sign convention used in figures and tables is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

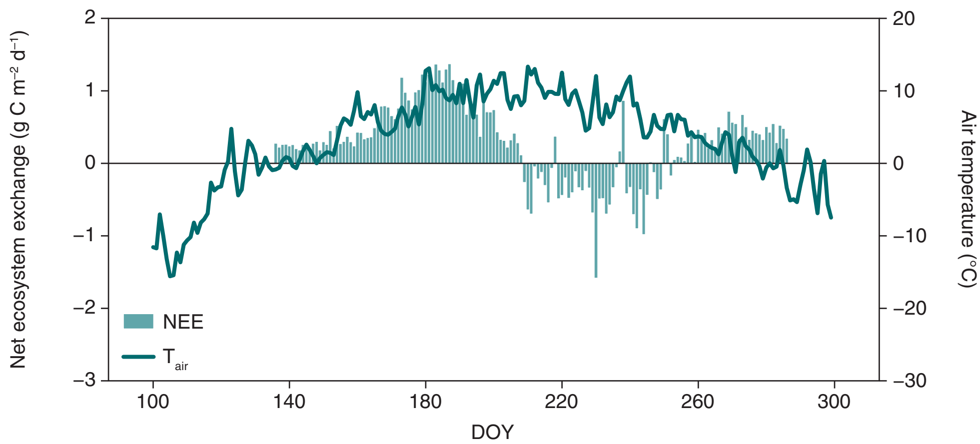


Figure 3.13 Diurnal net ecosystem exchange (NEE) and air temperature (T_{air}) measured in the fen in 2011.

Table 3.9 Summary of the eddy covariance measurement periods and CO_2 exchanges at the fen site. Please note that the measurement period varies from year to year.

Year	2008	2009	2010	2011
Measurements start	5 Jun	15 May	4 May	15 May
Measurements end	29 Oct	31 Oct	9 Oct	14 Oct
Start of net uptake period	–	1 Jul	29 May	28 Jul
End of net uptake period	16 Aug	27 Aug	18 Aug	7 Sep
NEE for measuring period (g C m^{-2})	–45.5	–14.0	–20.9	42.6
NEE for net uptake period (g C m^{-2})	–	–42.5	–65.4	–14.3
Max. daily accumulation (g C m^{-2} d^{-1})	–2.27	–1.48	–3.14	–1.58

Eddy covariance measurements of the CO_2 and H_2O exchange in the fen were initiated 15 May and lasted until 14 October. During this period, 9% of data were lost due to malfunction, maintenance and calibration. The eddy mast (2.2 m above ground) was fixed to the ground and when measurements started the snow depth in the fen was approximately 0.9 m. The fen was snowfree 12 June, during the snow covered period the daily CO_2 emissions were approximately 0.3 g C m^{-2} d^{-1}. After snow had disappeared, emissions increased and peak emissions were observed in early July, amounting to 1.37 g C m^{-2} d^{-1}. As the vegetation developed, the photosynthetic uptake of CO_2 started, and 28 July the fen ecosystem switched from being a net source to a net sink of atmospheric CO_2 on a daily basis. This is by far the latest onset of net uptake period measured.

The period with net CO_2 uptake in 2011 lasted until 7 September, which was the latest ending on record. During this period, the fen accumulated -14.3 g C m^{-2}, and maximum daily accumulation rate amounted to -1.6 g C m^{-2} (measured 18 August). The CO_2 accumulation during the net CO_2 uptake period in 2011 is lower than in previous years, which is likely caused by late snow melt and onset of growing season in combination with low levels of photosynthetic active radiation. By 7 September, respiration processes exceeded the fading photosynthesis and the ecosystem returned to a net source of atmospheric CO_2. In the beginning of this period, there was plenty of fresh litter available and soil temperatures remain comparably high, allowing decomposition processes to continue at a decent rate. Highest daily emission during autumn was measured 26 September (0.72 g C m^{-2} d^{-1}). During the entire measuring period (152 days) the fen constituted a fairly strong source for atmospheric CO_2, amounting to 42.6 g C m^2.

4 NUUK BASIC

The BioBasis Programme

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This chapter presents the results of the fifth year of the BioBasis monitoring programme at Nuuk. The chapter gives an overview of the activities and presents examples of the results. The programme aims at providing long-term data series on biotic variables from the Kobbefjord area approximately 20 km southeast of Nuuk. A thorough statistical analysis will follow, when we have longer time series. Methods and sampling procedures are described in detail in the manual 'Conceptual design and sampling procedures of the biological programme of Nuuk Basic', which can be downloaded from www.nuuk-basic.dk.

The programme was initiated in 2007 by the National Environmental Research Institute (now Department of Bioscience), Aarhus University in cooperation with the Greenland Institute of Natural Resources. BioBasis is funded by the Environmental Protection Agency as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. The authors are solely responsible for all results and conclusions presented in this chapter, which do not necessarily reflect the position of the Environmental Protection Agency.

4.1 Vegetation

Reproductive phenology

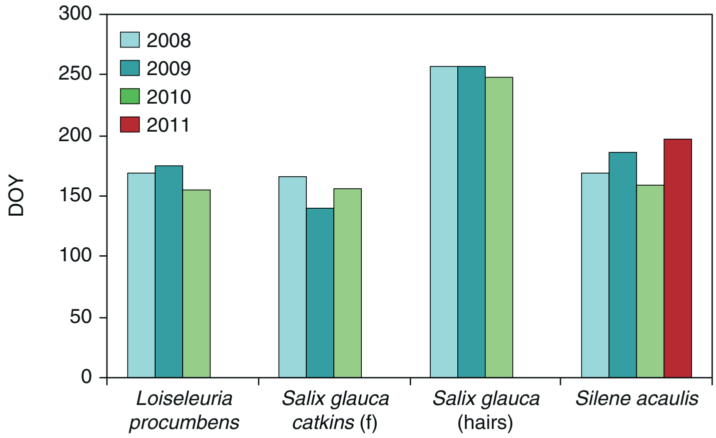
The reproductive phenology has been studied since 2008 on three vascular plant species: The evergreen dwarf shrub *Loiseleuria procumbens*, the herb *Silene acaulis* and the shrub *Salix glauca*. For each species, four phenology plots were set up to cover the ecological amplitude of the species with respect to snow cover, soil moisture and altitude. Due to late snow melt, the recording of reproductive phenology started 1 June and ended 4 October.

The buds of all the monitoring species were heavily impacted by larvae of the noctuid moth, *Eurois occulta*. This is the second year in a row with impact of this butterfly species. The number of larvae peaked in mid-July.

The first flowers of *L. procumbens* were seen 6 June just after snow melt outside the research cabin at Kobbefjord. The first record of budding in the *L. procumbens* plots was 10 June. Because of the larvae impact, it was only possible to record the time of 50 % flowering of *Silene acaulis*, which is the latest date of 50 % flowering ever recorded during the years of monitoring (figure 4.1).

The number of buds of *Loiseleuria procumbens* peaked few days later than in 2009 and four weeks later than the earliest year 2010 (figure 4.2a). A maximum of 1366 buds was recorded 22 June, which is the largest number since the monitoring programme started. However, all buds were grazed by the larvae and no flowers developed. Contrary to the re-budding after the larval impact in 2010, no new buds emerged in 2011 (figure 4.2). The time of the peak number of buds varies when comparing the years 2008-2011. In 2010, the earliest snow free year, the peak of buds was 19 May (DOY = 139), com-

*Figure 4.1 Mean value for days of year (DOY) of 50% flowers/catkins for each of the species (*Loiseleuria procumbens, Salix glauca*, and* Silene acaulis*) in the plant reproductive phenology plots for 2008-2011. Also included are the senescent catkins of* Salix glauca*. An error in the figure in the 2010 report has been corrected.*



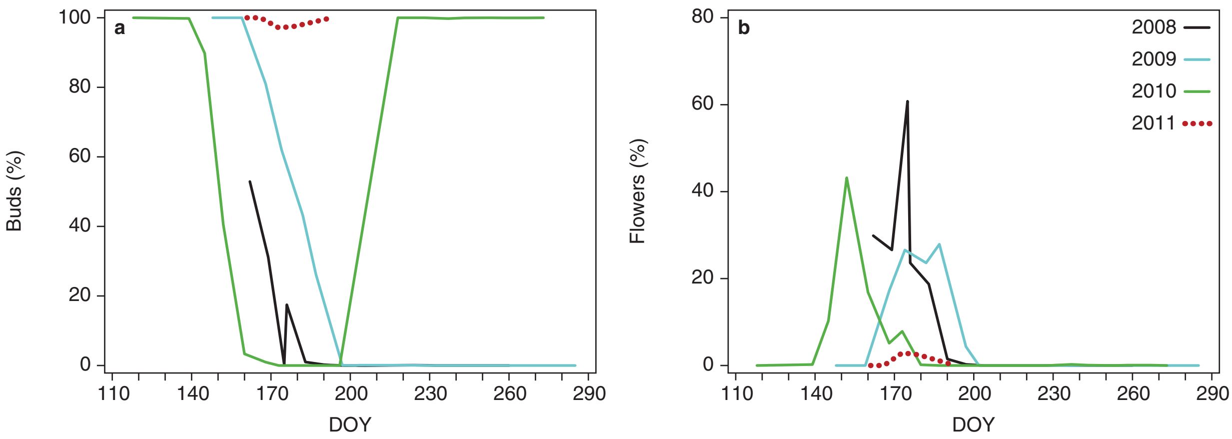


Figure 4.2 a) Numbers of Loiseleuria procumbens *buds during the growing seasons of 2008-2011. b) Number of* Loiseleuria procumbens *flowers during the growing seasons 2008-2011.*

pared to 10 June (DOY = 162), 8 June (DOY = 159), and 22 June (DOY = 173) in 2008, 2009, and 2011, respectively. Hence, the peak of *L. procumbens* buds was approximately four weeks later in 2011 compared to the early snow free year 2010. In 2010, the plants started to produce buds later in the growing season following the larvae impact ending with a total number of new buds at the same magnitude as earlier in the season.

The number of *Silene acaulis* buds peaked 28 June (DOY = 179) and the timing is comparable to the 2009 season, but with less than half of the number of buds (figure 4.3a). The production of new buds after the larvae impact was approximately two weeks later compared to 2010, where larvae also impacted the spring budding. The number of late buds in 2011 was higher (308 buds 20 September, DOY = 263) than the number of early buds (253 buds 28 June, DOY = 179). Despite the number of buds the number of flowers was the lowest ever recorded with only 1/10 of the maximum number recorded in 2008 (figure 4.3B).

Salix glauca was the monitored species most impacted by the larvae (figure 4.4). No buds or female catkins were produced early in the season and after the larvae impact only few new buds were produced very late (mid-September) resulting in just one male in fluorescence in one plot (SAL4B).

Phenology of *Salix glauca* in CO_2-flux plots

No *Salix glauca* buds or catkins were recorded in the CO_2 flux plots due to the grazing by *Eurois occulta* larvae.

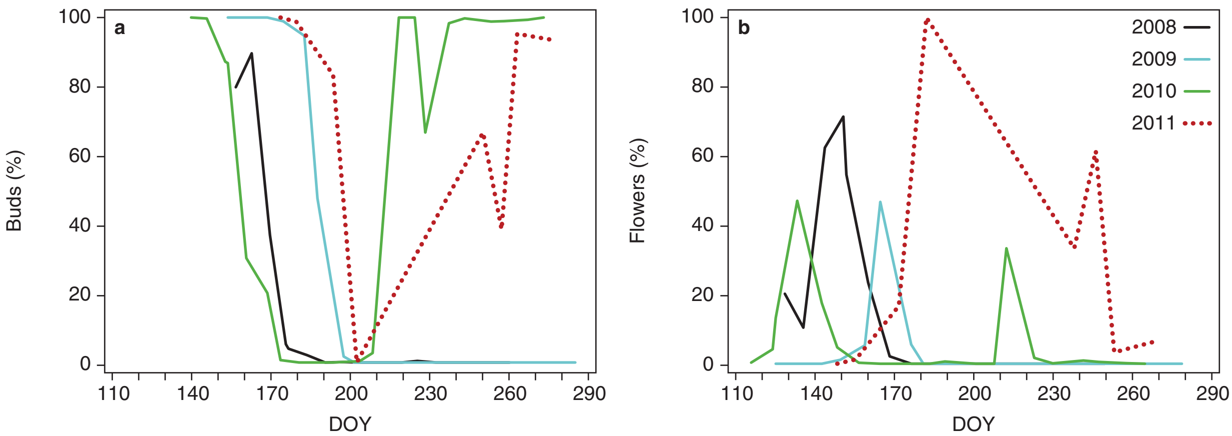
Total flowering

No counts of total flowering were carried out since only few of the buds of the monitored species developed into flowers due to the impact by *Eurois occulta* larvae.

Impact of the noctuid moth *Eurois occulta*

The vegetation in the Kobbefjord area was heavily impacted by larvae of the noctuid moth *Eurois occulta* during the 2011 season. The effect of the larvae was more severe compared to the 2010 season, which was the first time a significant impact was recorded in the area. The larvae affected the production of leaves, buds and flowers or catkins. Hence, reproduction in

Figure 4.3 a) Number of Silene acaulis *buds during the growing seasons 2008-2011. b) Number of* Silene acaulis *flowers during the growing seasons 2008-2011.*



our phenology plots, CO_2 flux plots, and in general the vegetation in the area was significantly reduced. Larvae along with other arthropods were collected weekly within our arthropod plots (Art1-4) and the number of larvae from Art3 has been counted. Art3 is dominated by low *Salix glauca* shrubs, which represents the dominating type of heath vegetation in the Kobbefjord area.

The number of larvae varied during the season with a peak of 1859 larvae in early July (figure 4.5). This number is 30 times larger than the peak in 2010. The outbreak of larvae resulted in the vegetation being defoliated from mid-July, and only late in the season the vegetation was able to produce new leaves as evident from the NDVI measurements.

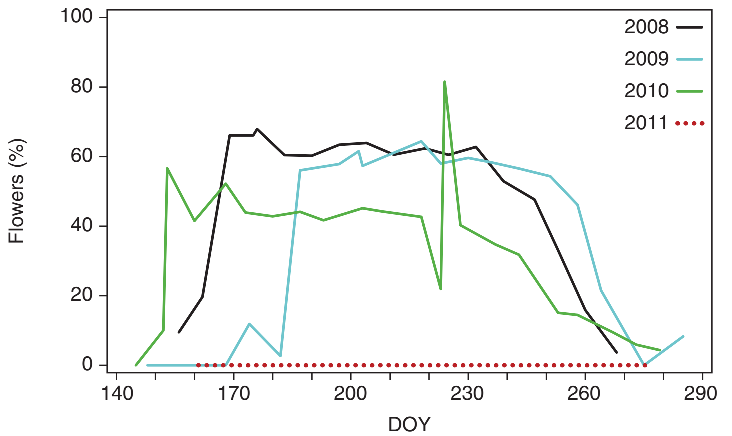


Figure 4.4 Number of Salix glauca *catkins during the growing seasons 2008-2011. Erratum: Figure 4.3A in NERO 4th Annual Report (Jensen and Rasch 2011) is not correct. The data has been recalculated and is shown correctly here.*

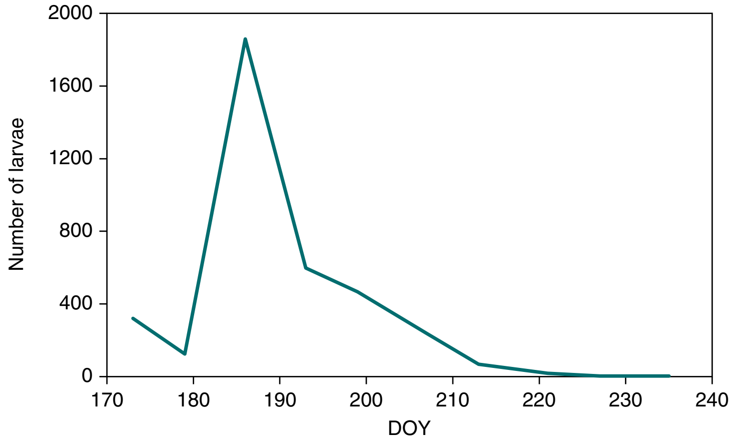


Figure 4.5 Number of Eurois occulta *larvae during the growing season 2011.*

Summing up reproductive plant phenology

A preliminary review of data related to flowering and plant reproductive phenology indicates that the 2011 season was characterized by:

- An impact of the noctuid moth *Eurois occulta* altering the phenology significantly for all the monitoring species
- Late budding due to late snow melt
- Low number of flowers in all species due to the larvae impact
- Re-budding in *Silene acaulis* and *Salix glauca* (only a few) late in the season.

Vegetation greening, NDVI

The seasonal greening of the vegetation was monitored in i) *Empetrum nigrum* ssp. *hermaphroditum* and *Eriophorum angustifolium* plots, ii) the plant phenology plots, and iii) along the NERO line (Bay et al. 2008). We used a handheld Crop Circle TM ACS-210 Plant Canopy Reflectance Sensor, which calculates the greening index (Normalized Difference Vegetation Index – NDVI). Measurements were made weekly in the *Empetrum nigrum* plots, *Eriophorum angustifolium* plots, and the plant phenology plots, and monthly along the NERO line.

NDVI in the *Empetrum nigrum*-, *Eriophorum angustifolium*-plots and plant phenology plots

There was a trend in three of the four plots of *Empetrum nigrum* as the NDVI values were lower during the complete growing season compared to the previous three years (figure 4.6a). However, there was a weak optimum in spring at the end of June (DOY = 175-180). The highest values were found in the end of the growing season in the beginning of October (DOY 275-280).

Comparing photos from 28 June to 7 September 2011 shows that the evergreen shrub had brown leaves after the snow melt in June, and that the general colour of the vegetation in the plots changed during the growing season and was green in September (figure 4.7). The *Empetrum nigrum* plot3 was snow free more than a month later in 2011 (22 June) compared to 2010 (19 May). This may have resulted in the browning of the leaves.

The general trend of *Eriophorum angustifolium* is increasing NDVI values during the season; though, the dates of the peak vary between years (figure 4.6B). In two plots, the NDVI value peaked in the end of August (plot 1, 2; DOY = 228, 243), one peaked at mid-September (plot 3; DOY = 257), and the last peaked at the last recording in the beginning of October (DOY = 278).

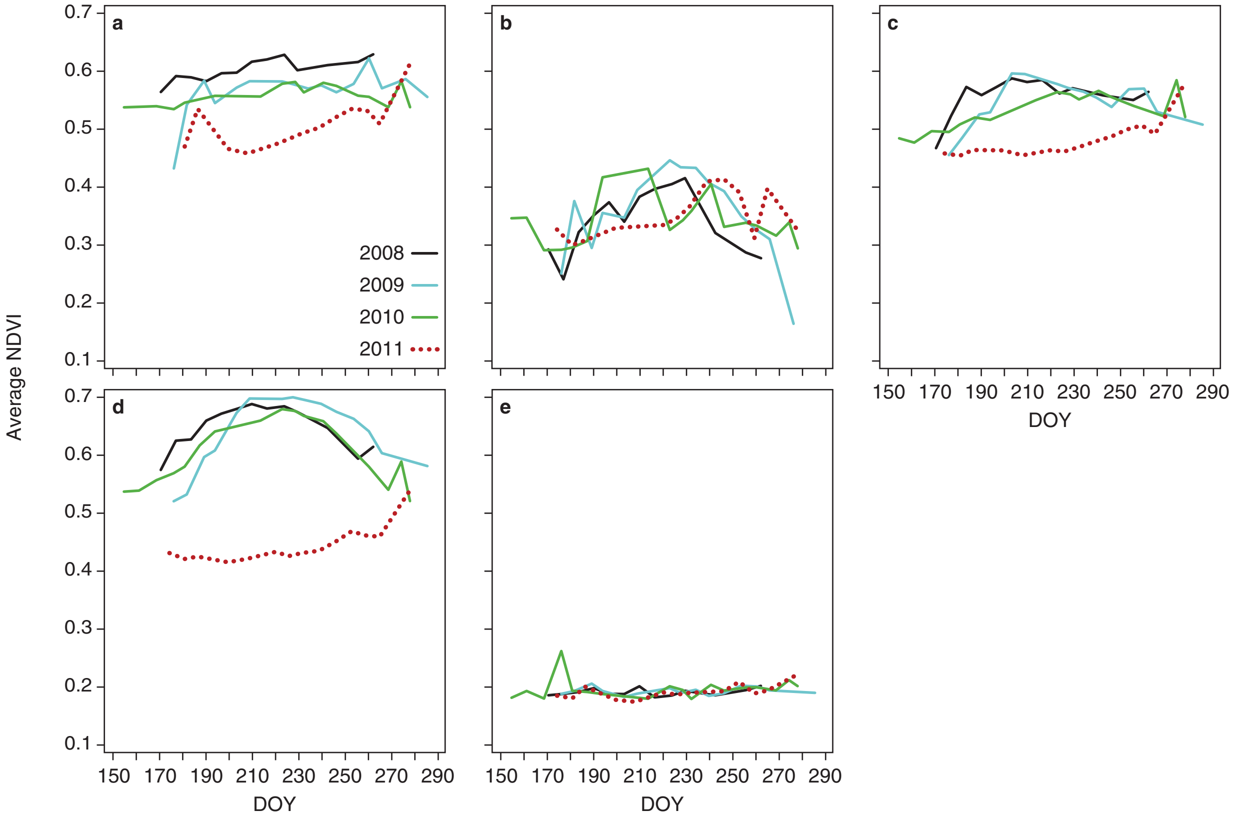


Figure 4.6 a) Average NDVI values in an Empetrum nigrum *plot during the growing seasons 2008-2011. b) Average NDVI values in an* Eriophorum angustifolium *plot during the growing seasons 2008-2011. c) Average NDVI values in a* Salix glauca *plot during the growing seasons 2008-2011. d) Average NDVI values in a* Loiseleuria procumbens *plot during the growing seasons 2008-2011. e) Average NDVI values in a* Silene acaulis *plot during the growing seasons 2008-2011.*

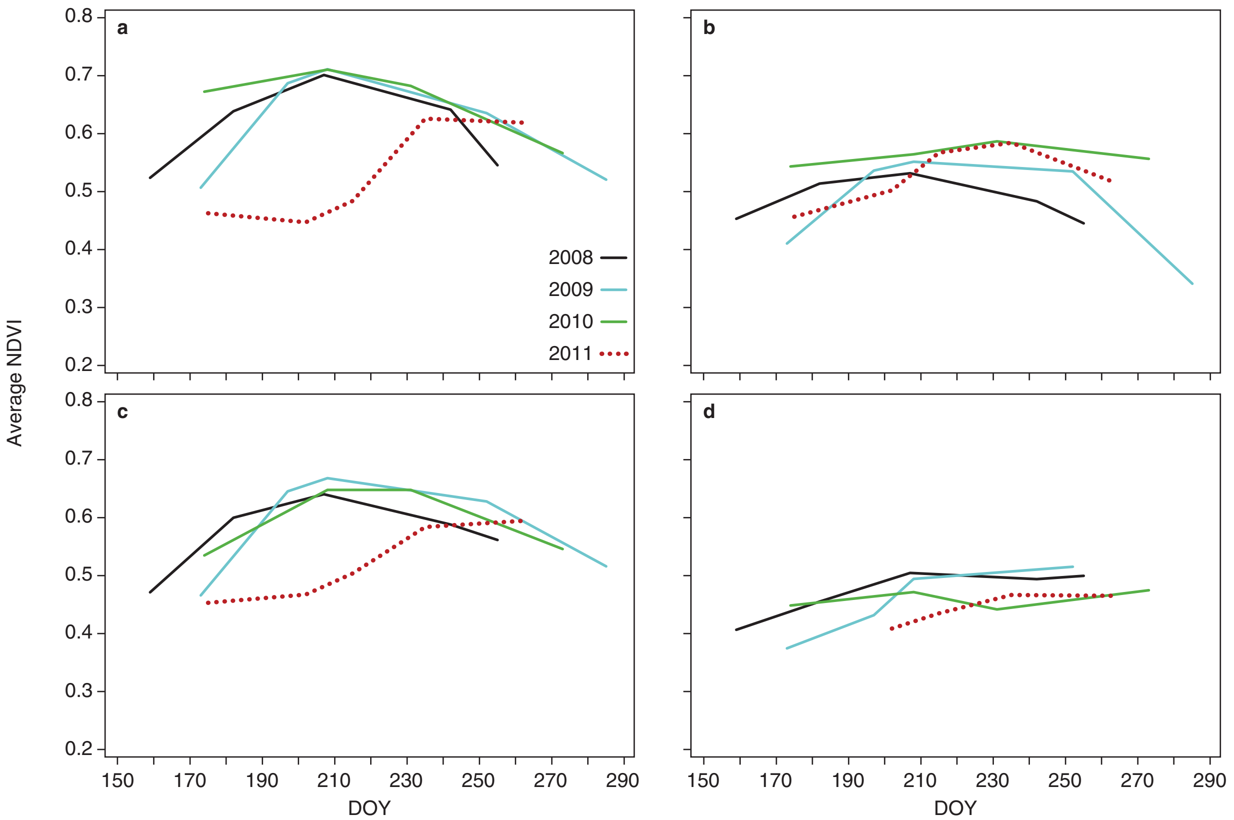


Figure 4.7 NDVI values along the NERO line from the vegetation types a) Dwarf shrub heath b) Copse c) Fen and d) Snow patch.

Loiseleuria procumbens exhibits the same trend as *E. angustifolium* by ending the season with the highest NDVI-values. Three of the four plots (plot 1-3) of *L. procumbens* have lower NDVI values during the season compared to previous years.

Salix glauca had significantly lower NDVI values than previous years with hardly any greening until the last part of the season (figure 4.6c).

Silene acaulis had generally very low NDVI values during the whole season and the values were similar to the previous three years (figure 4.6d). The NDVI peaked at the last recording in early October.

NDVI along the NERO line

Generally, the NDVI values along the NERO line in the heaths and the copses were lower than the previous years, especially in the beginning of the season (figure 4.7a and 4.7b). The greening reached the level from previous years in late August (DOY = 235). The NDVI values peaked in the heaths in the end of September (DOY = 265). The fen plot (figure 4.7c) reached the peak of NDVI in the end of August (DOY = 235) later than in previous years and the greening was slower in the beginning of the growing season presumably due to the late snow melt.

The recording started three weeks later in the snow patch vegetation (figure 4.7d) because of the late snow melt and the NDVI values were lower than in 2008-2009, but at the same level as in 2010.

Summing up the vegetation greening

Generally, the NDVI values were significantly lower than previous years. This is presumably caused by the heavy impact of the larvae.

Carbon dioxide exchange

In 2008, a manipulation experiment was initialized using five treatments, each with six replicates. The experiment is located in a mesic dwarf shrub heath dominated by *Empetrum nigrum* with *Salix glauca* as a subdominant species. Treatments include control (C), shortened growing season (SG: addition of snow in spring), prolonged growing season (LG: removal of snow in spring), shading (S: hessian tents) and increased temperature (T: ITEX Plexiglas hexagons). We have conducted measurements of land-atmosphere exchange of CO_2 using the closed chamber technique, soil temperature, soil moisture, and phenology of *Salix glauca* approximately every week from June to October each year. The net ecosystem exchange (NEE) was measured with transparent chambers, while the ecosystem respiration (R_{eco}) was measured with darkened chambers. The SG and LG treatments have not been applied in 2008-2011, so results from these plots can be considered controls.

Fifteen CO_2 flux measurements were carried out from 17 June to 14 October. Generally, all plots functioned as sinks for atmospheric CO_2 at the time of the measurement (midday, between 10 am and 3 pm) in August and September (figure 4.8). In June, July and October fluxes were close to zero, except for T-plots that on average were sources of CO_2 in June and July. Similar to earlier years, NEE was more negative (i.e. higher CO_2 up-

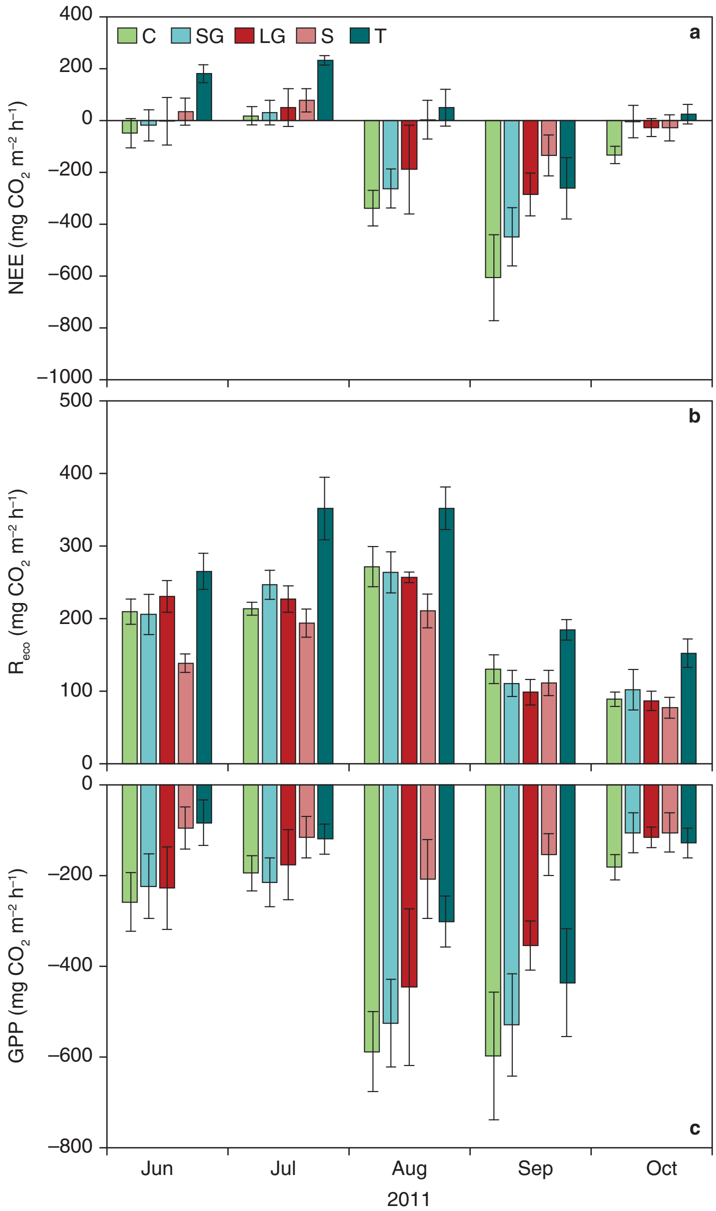


Figure 4.8 a) Monthly means of net ecosystem exchange (NEE), b) ecosystem respiration (R_{eco}) and c) gross primary production (GPP) in 2011 in the manipulation experiment. Error bars refer to standard error in spatial variability (six replicates). For explanation of treatment abbreviations, see the text.

take) in C-plots compared with T- and S-plots. The ecosystem respiration showed a constant pattern of higher emissions in T-plots compared with other treatments, which can be explained by warmer and drier conditions leading to increased respiration rates. The highest rates of gross primary production (GPP: difference between NEE and R_{eco}) were generally observed in C-plots, while especially S-plots showed lower GPP rates compared with other treatments. As photosynthesis is driven by solar radiation, shading decreases GPP and build-up of biomass.

The differences between treatments are in general similar to measurements in previous years. However, the CO_2 uptake is distinctly lower compared with previous years. It is likely that the low GPP rates were caused by a combination of the late snow melt resulting in a short growing season and the outbreak of the larvae *Eurois occulta* that defoliated large parts of the heath vegetation.

UV-B exclusion plots

Measurements of chlorophyll fluorescence as a measure of plant stress were not carried out in the Kobbefjord area in 2011. This was due to the vegetation being heavily impacted by the larvae of *Eurois occulta*. Leaves of both *Betula nana* and *Vaccinium uliginosum* were grazed and they re-grew only slowly late in the season. Frames with Mylar film for 60% reduction in UV-B influx and Teflon film (control film) were established 13 July and taken down in late August.

4.2 Arthropods

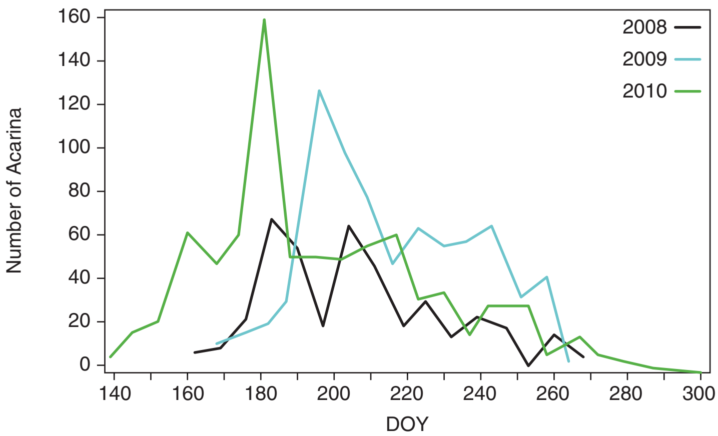
As part of the zoological monitoring programme four pitfall trap stations with a total of 32 pitfalls were established in 2007. In addition, two window trap stations each with two traps were established in 2010. All traps were open during the 2011 season with a total of 3496 trap-days covering the period 22 June-20 September. The samples from 2008-2010 are currently being sorted by Department of Bioscience, Aarhus University, Denmark. Samples collected in 2011 are stored in 70% ethanol at Greenland Institute of Natural Resources.

The material from 2010 has been sorted into the following taxonomical groups: Lycosidae, Acarina, Collembola, Simulidae, Muscidae, Chironomidae, Ichneumonidae, Chalcidoidea, Ceratoponidae, Anthomyiidae, Tachinidae, Sciaridae and two have been identified to the species level: *Mitopus morio* and *Nysius groenlandicus*.

The preliminary results from the period 2008-2010 of the most abundant group the Acarina, are presented in figure 4.9.

In general, there are huge variations in the number of trapped specimen within all taxonomical groups both within the season and between years. The peak number of specimens trapped is often reached in the beginning of the season. The most abundant group is the Acarina, which peaks with more than 160 specimens trapped during one week. The seasons differ in respect to the date of maximum catch. 2010 was the earliest (June 30, DOY 181) followed by 2008 (2 July, DOY 183), and 2009 (15 July, DOY 196).

Figure 4.9 Number of Acarina caught during the monitoring periods of 2008-2010.



Microarthropods and arthropod isotope campaign

Introduction

An increasing number of studies have applied analysis of natural abundance of stable isotopes to soil invertebrate communities and primary producers. The concept relies on the fractionation of stable isotopes when they traverse through food chains. When a food item is consumed, the enzymatic processes will discriminate between molecules with the light and heavy isotope and typically process less of the heavy molecule, which leaves more of the heavy isotope in the body of the consumer.

Sampling programme

Soil, turf and detritus samples for determination of natural abundance of stable isotopes in invertebrates were sampled in selected plots from 1 August to 12 August 2011: MArt2, MArt4 and MArt5 representing the three plant communities with *Empetrum nigrum*, *Salix glauca*, and *Silene*

Table 4.1 Inventory of the collected species or higher order of taxonomic groups and organic material from the monitoring plots in the Kobbefjord area (a number indicates a species not yet identified). Em) Empetrum nigrum *Sa)* Salix glauca *Si)* Silene acaulis.

	$\delta^{15}N$ and $\delta^{13}C$	Habitat		
Collembola				
Tetracanthella arctica	×	Em	Sa	Si
Desoria olivacea, adults and juveniles	×		Sa	
Desoria tolya		Em	Sa	
Parisotoma notabilis	×		Sa	
Isotomiella minor	×		Sa	
Folsomia quadrioculata	×	Em	Sa	
Folsomia sp.		Em		
Isotoma cf. *caerulea*	×	Em		
Lepidocyrtus violaceus	×			Si
Oligaphorura sp.			Sa	
Mesaphorura sp.		Em		Si
Willemia sp.				Si
Micranuridae pygmaea		Em		
Neanura muscorum		Em		
Symphyleona, 2 species		Em	Sa	
Mites				
Oribatida				
Nothrus pratensis	×	Em	Sa	
Melanozetes interruptus	×	Em	Sa	
Mycobates tridactylus (two varieties)	×	Em		Si
Platynothrus peltifer (interlamellar setae deviant)	×		Sa	
Carabodes labyrinthicus	×	Em		Si
Oribatula tibialis	×	Em		Si
Actinedida				
Actinedid sp.	×	Em		Si
Trombidiidae (mixture of velvet mites)	×	Em	Sa	Si
Gamasida				
1 Unknown species	×		Sa	
2 Unknown species mix	×	Em	Sa	Si
Spiders				
Linyphiidae several species	×	Em	Sa	Si
Pardosa hyperborea	×	Em		
Thanatus arcticus	×	Em		
Xysticus durus	×	Em		
Arachnid cf. (*Amaurobius* sp.)	×			Si
Pardosa groenlandica	×			Si
Arctosa insignita	×			Si
Beetles				
Coccinellidae	×			Si
Curculionidae larvae	×			Si
Carabid larvae	×	Sa		
Scarabaeus sp. larvae	×			Si
Various insects				
Coccoidea	×	Em	Sa	Si
Sciaridae	×	Em	Sa	Si
Eurois occulta	×			Si
Aphidoidea mixture	×			Si
Nysius groenlandicus				Si
Plants				
Carex bigelowii, fresh, senescent or roots	×	Em	Sa	

Empetrum nigrum ssp. *hermaphroditum*, leaves, twigs or roots	×	Em	Sa	Si
Juncus trifidus	×	Em		
Moss	×	Em	Sa	
Poaceae, shoot or root	×			Si
Vaccinium uliginosum, senescent leaves	×		Sa	
Other				
Dendrobena octaedra, adults and juveniles	×	Em	Sa	
Enchytraeids (*Enchytraeus albidus*) in seaweed	×			
Seaweed	×			
Decomposing seaweed	×			
Lichens	×	Em		Si
Peat/humus	×		Sa	
Roots in peat	×		Sa	

acaulis, respectively. The fourth monitoring habitat characterized by *Loiseleuria procumbens* was not included because it was very similar to the *Silene acaulis* habitat.

Table 4.1 is an inventory list of types of organisms and material collected for stable isotopic analyses. While some of the smaller organisms did not meet the minimum requirement of approximately 1 mg dry biomass for isotopic analyses, they were still included to demonstrate the species diversity and to compare population densities between years (the first sampling in August 2007).

In total 3670 individual invertebrates were identified to the highest possible taxonomic level by the sampling team, and then dried at 50 °C and wrapped into tin-capsules for isotope analyses at the UCDavis – Stable Isotope Facility, University of California, USA.

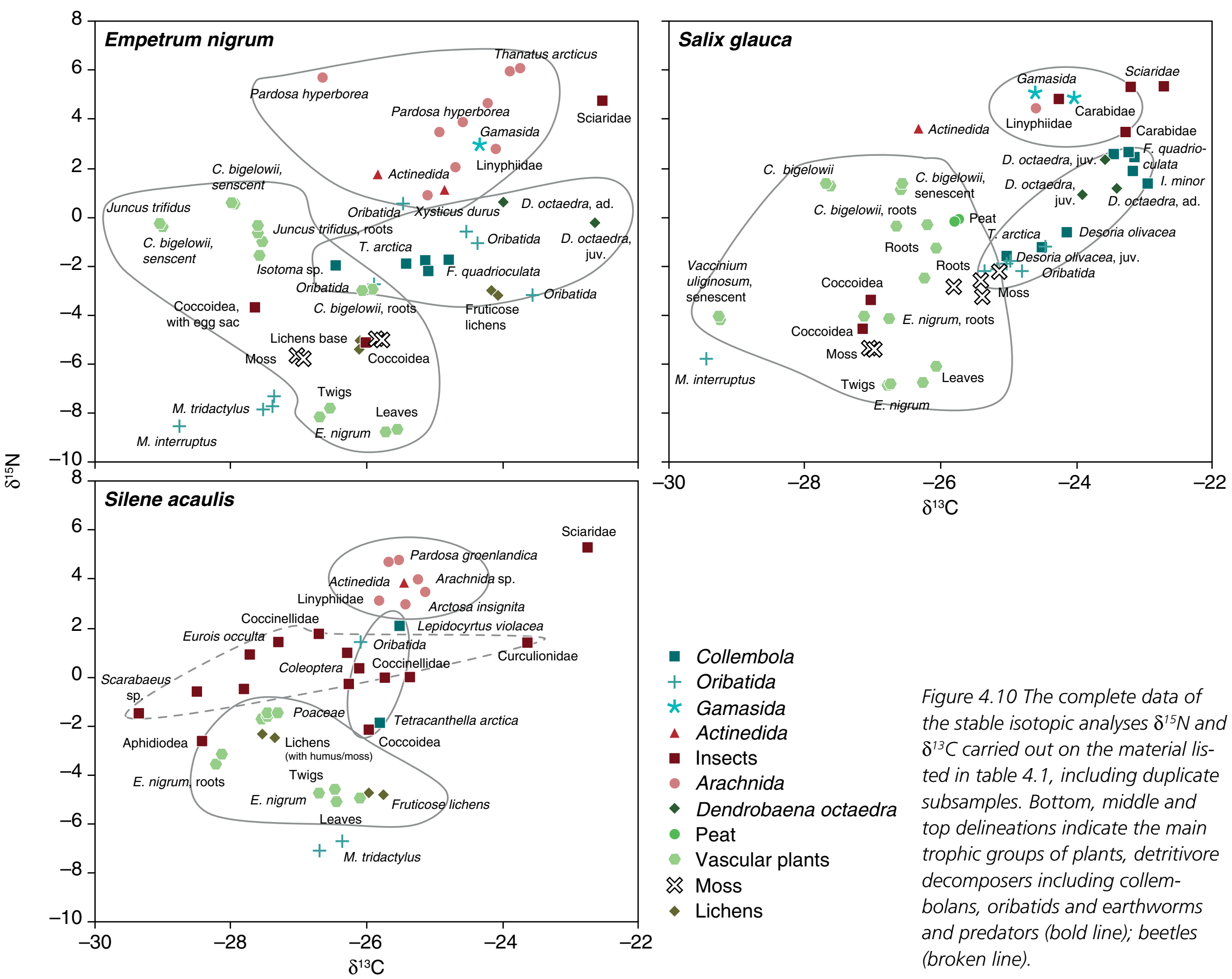


Figure 4.10 The complete data of the stable isotopic analyses δ15N and δ13C carried out on the material listed in table 4.1, including duplicate subsamples. Bottom, middle and top delineations indicate the main trophic groups of plants, detritivore decomposers including collembolans, oribatids and earthworms and predators (bold line); beetles (broken line).

Interpretation of stable isotope signatures

In the present interpretation, δ^{15}N was used as the main indicator of trophic position, although marked trends were clearly visible for δ^{13}C (figure 4.10), but not discussed here. Gross food web compartments are delineated in figure 4.10 illustrating that primary producers, herbivores, decomposers and predators create a seemingly complete food web. Herbivore insects are delineated into one cluster together with plants. The presented data will act as a baseline for comparison for future changes of the food web structure. The *S. acaulis* community revealed itself as the most ecologically simple as the plants and lichens spanned only 3.5 ‰ δ^{15}N, indicating that the sources of nitrogen were limited compared to the two other habitats with a more diverse plant community and a broader δ^{15}N range of about 9‰. Moreover, the higher level of δ^{15}N in *E. nigrum* and *S. glauca* communities indicate that the source of plant N-uptake is coming from processed nitrogen, i.e. through microorganisms and therefore relies on internal nitrogen recycling. This agrees with the conception of the Arctic heath community being nutrient poor favouring plant species that have particular means of coping with this condition such as symbiosis with mycorrhiza and efficient retention of nutrients. This is true for *E. nigrum* and *Vaccinium uliginosum*.

Collembolans spanned 5 ‰ δ^{15}N from -2 ‰ to 3 ‰ comprising oribatids and earthworm decomposers, although some oribatids and the collembolan *Tetracanthella arctica* may also eat plant material as they have the lowest δ^{15}N of this group.

The epigeic earthworm *Dendrobaena octraedra* may rely more on detrital material because it would otherwise be expected to have a lower δ^{15}N than 0-2 ‰.

As stressed by Maraun et al. 2011 oriba-tids may span four trophic levels. We found a δ^{15}N range of 9 ‰ due to *Melanozetes interruptus* having the lowest observed δ^{15}N and δ^{13}C of -8.6 ‰ and -29.5 ‰, respectively (n = 50 individuals). *Mycobates tridactylus* were next to *M. interuptus* with very low δ^{15}N of -7.9 ‰, while its δ^{13}C of -27.5 ‰ were comparable to other herbivorous arthropods such as Coccoidea. They are both ceratozetoids known to be associated with moss and lichens. As lichens have potentially very low δ^{15}N around -9 ‰ (Fischer et al. 2010), although we did not encounter lichens with δ^{15}N less than -6 ‰, *M. interuptus* may have consumed or assimilated nitrogen from selected parts of the lichen to obtain -8.6 ‰. It seems unlikely that fractionation should lead to depletion of ^{15}N in *M. interuptus* opposite to all other arthropods. The ceratozetoids were found to have similar extremely low δ^{15}N by Fischer et al. 2010 as *Mycobates parmeliae* had δ^{15}N at -10 ‰.

Seashore ecology

The signature of littoral enchytraeids at the Kobbefjord seashore and their seaweed food- and habitat base was determined to illustrate the essential information conveyed by the stable isotopic analysis. δ^{13}C of estuarine eulittoral marine phytoplankton and kelp such as *Laminaria digitata* is in the order of our observation of -18 ‰ to -17 ‰ (Cloern et al. 2002, Schaal et al. 2012). The increase in N of the decomposing seaweed exemplifies the increase in food quality of a low nitrogen seaweed source of 22 C/N, when microbial biomass uses external nitrogen it is decreasing its C/N to 13.

4.3 Birds

Survey for breeding passerines

No data available

Bird census points

Passerines were counted at 13 census points within the 32 km^2 Kobbefjord catchment area. Fourteen censuses were carried out from 8 June to 4 October 2011. When arriving at a census point five minutes were used as a "settling period" (initial period) and a following five minutes period (observation period) was used for counting the birds.

The total number of Lapland buntings (LB), snow buntings (SB), northern wheatears (NW) and redpolls (RP) varies between the years (table 4.2). Figure 4.11 shows the number of passerine counted per census from 2008-2011.

Table 4.2 The total number of passerines counted and the number of censuses per year.

Year	LB	SB	NW	RP	No. of censuses
2008	57	61	44	7	9
2009	39	40	33	37	5
2010	182	152	110	49	17
2011	166	131	146	7	14

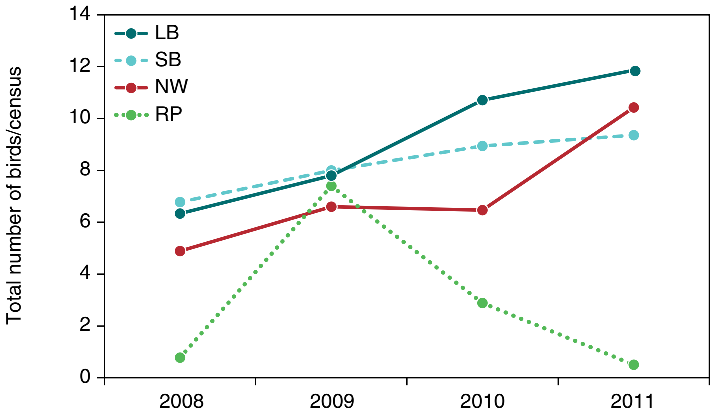


Figure 4.11 The total number of birds counted per census in 2008-2011. For explanation of the bird abbreviations, please see the text.

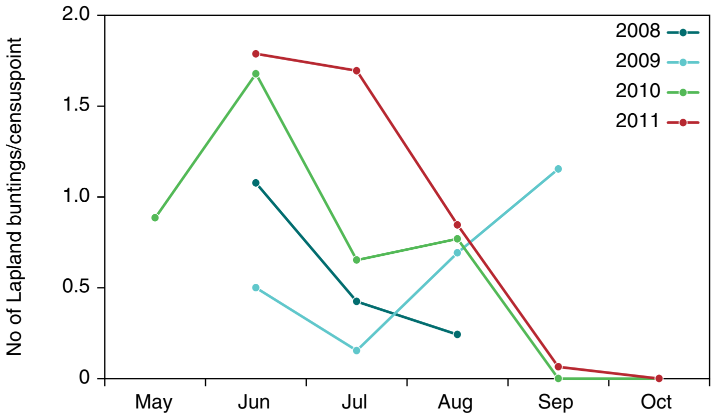


Figure 4.12 The number of Lapland buntings per census point during the season in 2008-2011. The lines connecting the dots are only used for illustrative purposes.

The most abundant passerine is the Lapland bunting. It arrives from winter quarters early in the spring (often before the first census of the year) and migrates to the winter habitats in August-September (figure 4.12). It is abundant and nesting in the entire area.

4.4 Mammals

The Kobbefjord catchment area is only sparsely populated with mammals. An Arctic hare was seen in Yderdal 15 May, and an Arctic fox (white morph) was observed close to Qassi-sø 9 September. Furthermore, tracks from Arctic foxes were seen in the snow during May and a set of caribou antlers was found en route to Yderdal 4 August.

4.5 Lakes

In the Kobbefjord catchment area, two of three lakes are monitored. Badesø and Qassi-sø are both deep with maximum depths of 35 and 27 meters, respectively. Badesø is situated downstream approximately 50 m a.s.l. and has an area of approximately 80 ha. The lake is oriented west-east and is relatively wind protected. Qassi-sø is located upstream approximate-ly 250 m a.s.l. and has an area of approximately 52 ha. A smaller glacier has its run-off into Qassi-sø. This lake is exposed to the prevailing south-westerly wind during summer and north-easterly wind during winter.

Full datasets are now available for the four-year period 2008-2011. Submerged macrophyte data are available from 2007-2011. Fish and macroinvertebrates have been sampled once in 2008 and will be sampled again in 2013.

Climate

The altitudinal difference between the two lakes causes a temperature difference, and the length of the ice free period varies consequently. On average, the ice free period

Table 4.3 Morphometric data, time weighted mean values of water chemistry and physical data measured in Badesø and Qassi-sø during the ice free periods from 2008 to 2011.

	Badesø				Qassi-sø			
Area (ha)	80				52			
Maximum depth (m)	35				27			
Mean depth (m)	9.2				7.8			
	2008	**2009**	**2010**	**2011**	**2008**	**2009**	**2010**	**2011**
Total phosphorus (mg l^{-1})	0.005 (0.001-0.012)	0.004 (0.003-0.005)	0.004 (0.003-0.004)	0.004 (0.003-0.005)	0.015 (0.005-0.029)	0.002 (0.001-0.005)	0.005 (0.003-0.009)	0.005 (0.003-0.006)
Total nitrogen (mg l^{-1})	0.084 (0.040-0.140)	0.027 (0.020-0.033)	0.080 (0.04-0.11)	0.17 (0.14-0.23)	0.090 (0.30-0.150)	0.022 (0.019-0.029)	0.084 (0.050-0.14)	0.138 (0.09-0.23)
pH	6.92 (6.59-7.13)	6.85 (6.46-7.14)	6.62 (6.09-7.3)	7.1 (6.51-7.85)	6.72 (6.44-6.96)	6.87 (6.79-6.93)	6.84 (6.37-7.31)	7.59 (6.79-7.97)
Conductivity (µS cm^{-1})	20 (19-22)	22 (21-23)	21 (18-26)	21 (15-27)	20 (15-24)	16 (16-17)	17 (15-18)	18 (15-20)
Ice free (date)	3 Jun	15 Jun	20 May	23 Jun	12 Jun	28 Jun	31 May	1 Jul
Ice covered (date)	24 Oct	30 Oct	13 Dec	25 Oct	18 Oct	17 Oct	10 Nov	20 Oct
Ice free period (days)	143	137	207	124	128	111	163	112

has been 26 days longer in Badesø than in Qassi-sø during the period 2008-2011, varying from 12 to 44 days with the largest difference observed during the warm year 2010 and the shortest difference observed in 2011 following the very long and cold winter 2010/2011 (table 4.3). Within-lake inter-annual variations also occurred in the ice free/ice covered periods (Nymand et al. 2011).The evaluation of ice coverage is based on overview photos taken daily of parts of the Kobbefjord catchment area (figure 4.13).

Figure 4.13 An example of 50% ice cover based on the overview photos of Qassi-sø. In 2011, following the long 2010/2011 winter, the lake was not ice free until 1 July. Photos: GeoBasis programme, Nuuk.

Chemistry

Both lakes are like most Arctic and semi-arctic lakes, oligotrophic with very low nutrient levels. Total phosphorus (TP) average concentrations vary between 0.002 and 0.015 mg l^{-1}, with maximum values up to 0.013 and 0.029 mg l^{-1} in Badesø and Qassi-sø, respectively (figure 4.14, table 4.3). Total nitrogen (TN) average concentrations are low too, varying between 0.020-0.170 mg l^{-1}, reaching maximum values of 0.23 mg l^{-1} in both lakes in 2011 (figure 4.14, table 4.3). Except for 2009, nitrogen levels have generally been increasing in both lakes. The atypical low nitrogen concentrations in 2009 can be explained by climatic conditions, since this year was very dry compared to the rest of the monitoring period, with 20-50% less precipitation (table 4.4), causing reduced run off and loading to the lakes. Overall conductivity is low and very constant throughout the monitored period (table 4.3).

Chlorophyll *a* and Secchi depth

Chlorophyll *a* (Chl *a*) is correlated to nutrient levels and the Chl *a* levels of the two lakes are consequently low (figure 4.15a). Chl *a* varied notably between the years, but compared to more nutrient rich lakes

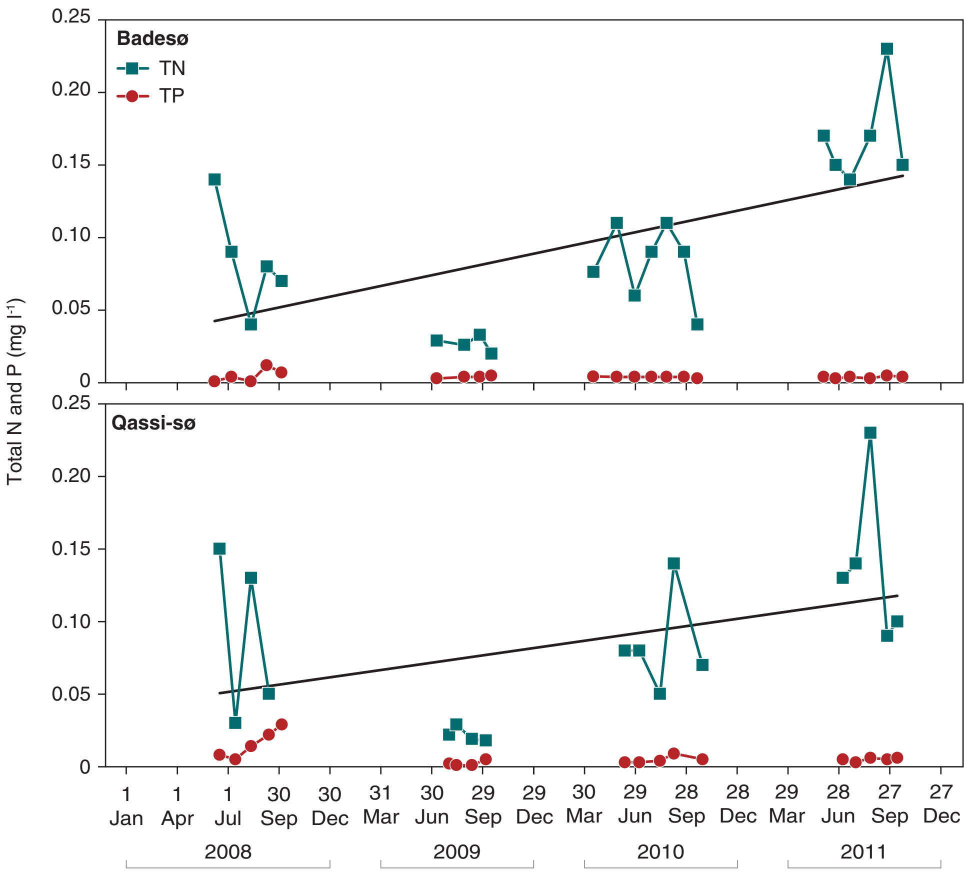


Figure 4.14 Total nitrogen (TN) and total phosphorus (TP) in Badesø and Qassi-sø during 2008 to 2011.

Table 4.4 Annual and summer (May-Aug.) precipitation and annual number of precipitation days from the official DMI station in Nuuk. A precipitation day is defined as a day with >1 mm precipitation.

Climate data from Nuuk	2008	2009	2010	2011
Annual precipitation (mm)	1041	537	733	748
Precipitation May-Aug (mm)	214	122	400	220
Annual precipitation days	134	82	102	123

the variation remains within a very narrow range due to the low nutrient levels. During the four-year period, Chl *a* exhibited an increasing trend in both Badesø and Qassi-sø despite a small Chl *a* reduction in 2011 compared to 2010 (figure 4.15a). In correspondence with this, a decreasing trend in Secchi depth occurred. In Badesø, the Secchi depth trend decreased from approximately 8 m to 5.5 m (figure 4.15b) during 2008 to 2011. In Qassi-sø, a Secchi depth reduction was observed, the trend declining from approximately 4.2 m to 3.0 m (figure 4.15b). The generally lower Secchi depth in Qassi-sø compared to Badesø is presumably due to the glacial run off causing more silt in Qassi-sø.

Zooplankton

Zooplankton consists of rotifers, calanoid copepods, cyclopoid copepods and cladocerans. In general, calanoid copepods together with the small rotifers dominate in both lakes, supplemented by particularly cyclopoid copepods in Qassi-sø in 2008 and 2010 (figure 4.16). However, cyclopoid copepods were also quite abundant in Badesø in 2008 and 2010.

Rotifers are typical in lakes with fish predation and in accordance to this; rotifers are slightly more abundant in the fish containing Badesø. In general, we find a lower zooplankton biomass in Badesø compared to Qassi-sø, also indicating a higher fish predation on zooplankton, since fish are size selective in their choice of prey, preferring the larger specimens of zooplankton. This is also reflected in the biomass based phytoplankton/zooplankton ratio (figure 4.17), which in general is lower in the fishless Qassi-sø compared to Badesø indicating a higher predation from the zooplankton on the phytoplankton biomass.

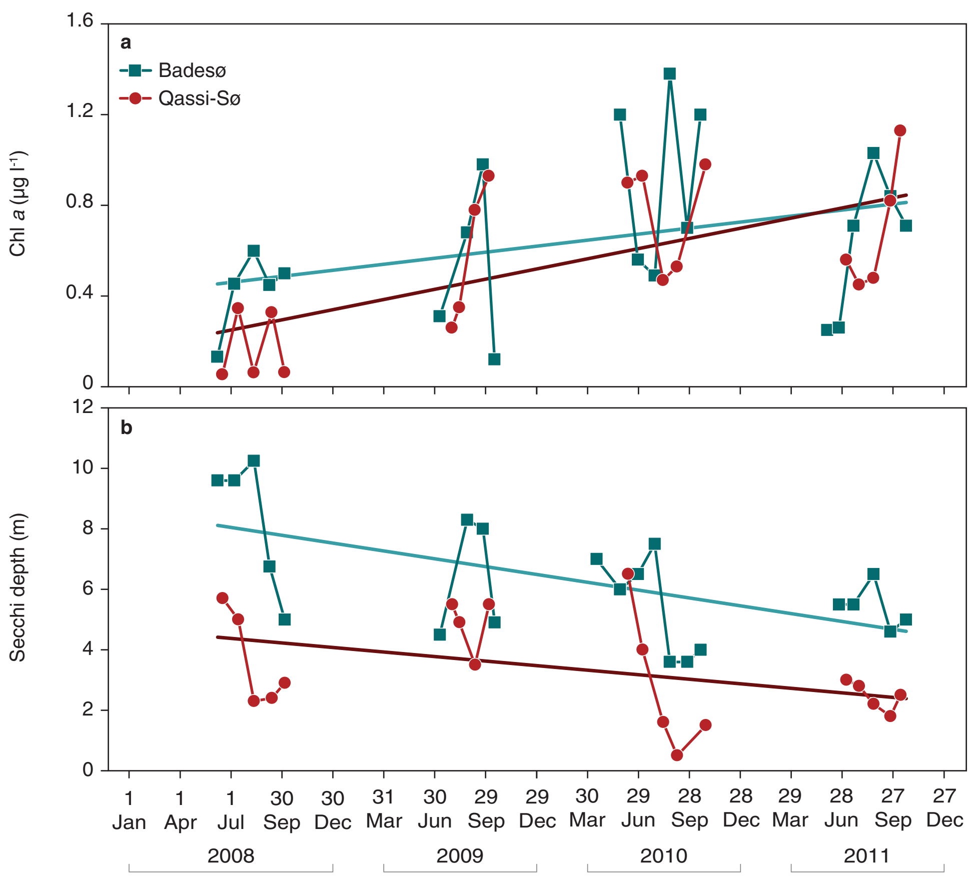


Figure 4.15 Chlorophyll a concentration (a) and Secchi depth (b) measured during the ice free period in Badesø and Qassi-sø from 2008 to 2011.

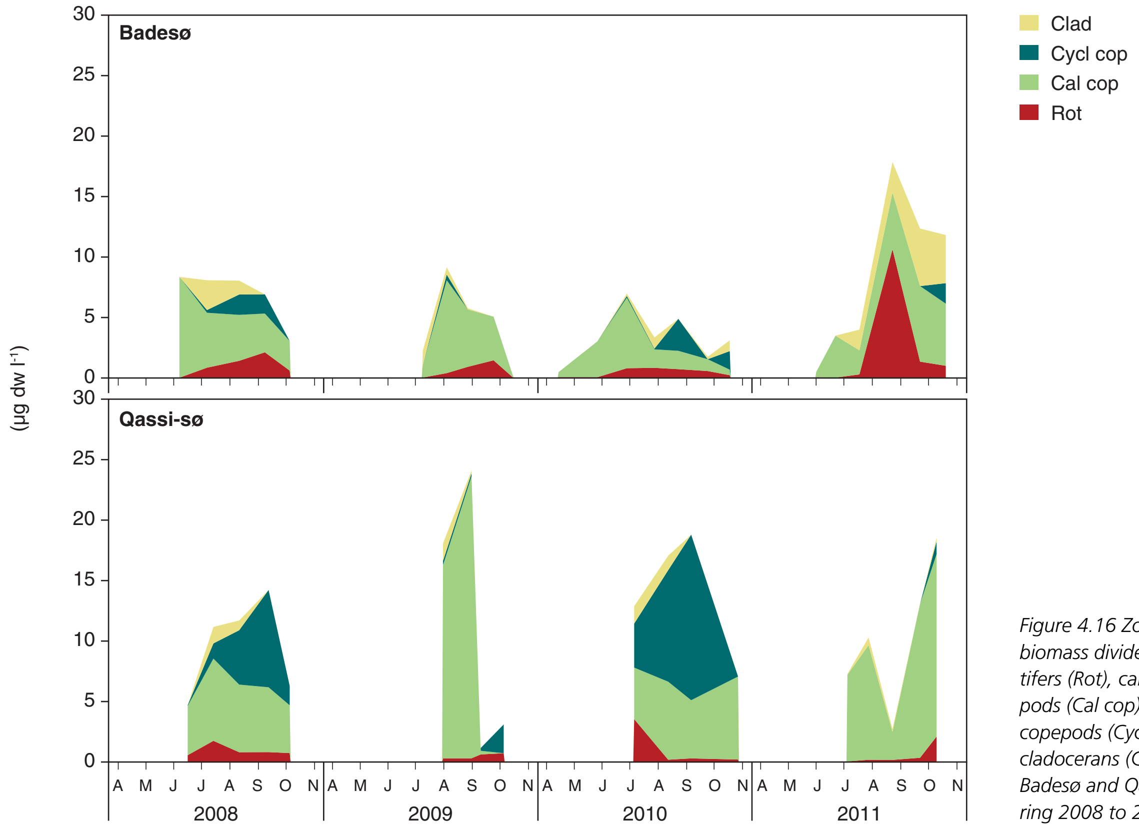


Figure 4.16 Zooplankton biomass divided into Rotifers (Rot), calanoid copepods (Cal cop), cyclopoid copepods (Cycl cop) and cladocerans (Clad) in Badesø and Qassi-sø during 2008 to 2011.

Submerged vegetation

During the entire monitoring period, macrophyte communities have been dominated by water starwort *Callitriche hamulata*, and secondarily by mosses. In 2011, the macrophyte coverage in Badesø was reduced (compared to the 2010-level, which was the highest measured level ever), to a level comparable to the year 2009. In general, the coverage was reduced in the deepest depth zones (table 4.5). However, in Qassi-sø the coverage was relatively high also in 2011 and at a similar level as in 2009 (table 4.5).

Due to the coverage reduction in the deepest depth zones in Badesø the depth limit of *C. hamulata* decreased in 2011 compared to 2010. The reduced depth limit in 2011 can be due to the very short growth period resulting from the long winter 2010/2011. Nevertheless, there is still an increasing trend in the vegetation depth limit during the five-year monitoring period (figure 4.18a). In Qassi-sø, the increasing trend in depth limit continued in 2011 and reached the highest depth limit for both water starwort and mosses (figure 4.18b).

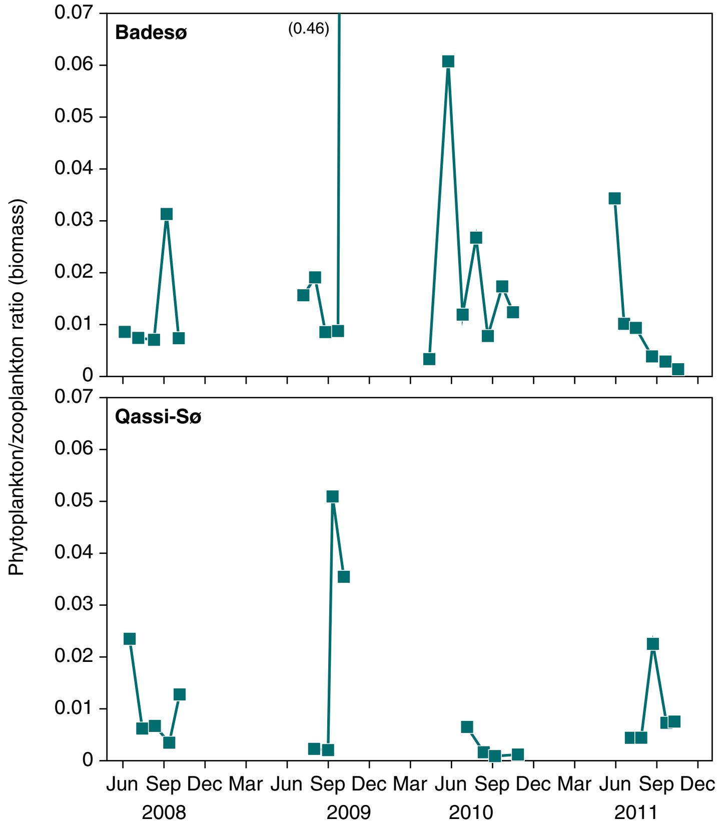


Figure 4.17 Phytoplankton/zooplankton ratio based on biomass in Badesø and Qassi-sø during 2008 to 2011.

Table 4.5 Macrophyte coverage (%) at 1 m depth intervals to a depth of 6 m from 2007-2011 in Badesø and Qassi-sø. Water starwort Callitriche hamulata *is shown at the top and mosses below. Macrophyte coverage (%) is measured once every year.*

		Badesø					Qassi-sø				
	M	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011
C. hamulata	1	0.6	10.1	6.5	8.4	3.1	0	0.18	3.6	0.2	1
	1-2	16	10.8	16.4	14	8.9	9.7	5.3	4.3	1	3.1
	2-3	34.8	18.7	11	25	31	11.3	1.4	24.8	12	21
	3-4	18.5	7.7	11.6	43	17	0.4	5.8	0.06	10	11.3
	4-5	37	21	1.5	26	7.3	0	0.4	2	0	5.4
	5-6	0	4.4	0.8	0	1.2	0.3	0	3.3	0.4	0
	>6	0	0	0.06	0.1	0	0	0	0.03	0	0.05
Moss	1	8.6	4.5	4.1	1.4	0.5	0	0	0	0	0
	1-2	2.8	5.5	7.2	0.3	2.9	0.12	1.3	0.74	0.7	0.2
	2-3	2	5.3	3.7	0.2	1.4	0	0	3.2	0.2	0.3
	3-4	0	8.7	13	0.3	0.3	0	0	0	0.2	0
	4-5	0	0	2.2	0.6	0	0	0	0	0.3	0.2
	5-6	0	1.6	0.9	0.3	0	0.3	0	0	0	0
	>6	0	0	0	0.2	0.1	0	0	0.03	0	0

We still cannot conclude on potential competition between the two species, but when *C. hamulata* expand, mosses will invariably decline (Nymand et al. 2011).

Summary, lakes

Both Badesø and Qassi-sø are oligotrophic lakes. However, the nitrogen level has been increasing during the past four years, except for the dry year 2009, where the nitrogen level was very low, probably due to a reduced nutrient run-off. During the four-year period, a slight increase in chlorophyll *a* and consequently a small decrease in Secchi depth have been observed. The decrease in Secchi depth has not affected macrophyte growth. Nor has the depth limit of the macrophyte growth been affected since the depth limit is slowly increasing particularly in Qassi-sø. The zooplankton community and biomass reflects the conditions in the two lakes. We find a higher zooplankton biomass in the fishless Qassi-sø indicating a small predation pressure on zooplankton and consequently a slightly lower phytoplankton/zooplankton ratio compared to Badesø that has fish and therefore a higher predation pressure on zooplankton. In a future warmer scenario, we may expect differences in the phyto-plankton/zooplankton ratio between the two lakes to increase, due to a higher productivity followed by a higher impact of fish on the zooplankton community in Badesø.

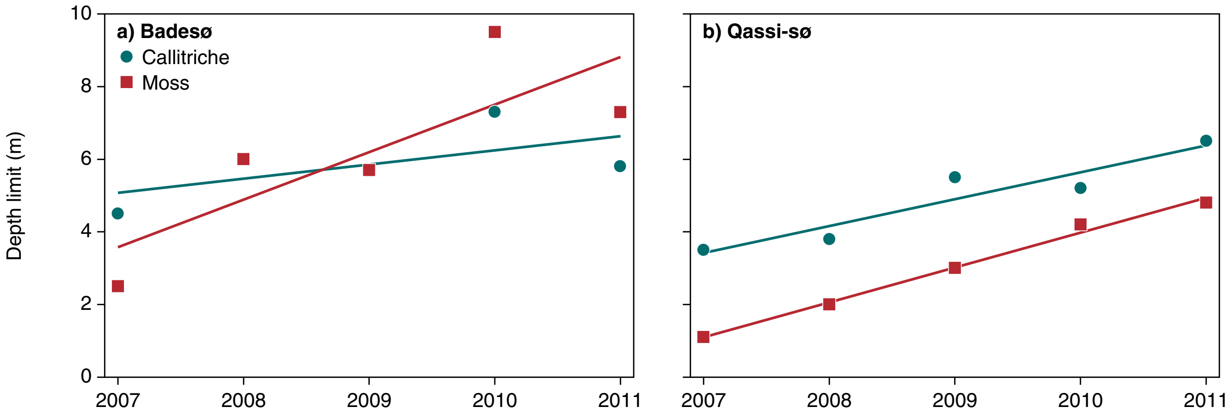


Figure 4.18 Depth limit for water starwort and mosses in a) Badesø and b) Qassi-sø, during the period 2007 to 2011.

5 NUUK BASIC

The MarineBasis Programme

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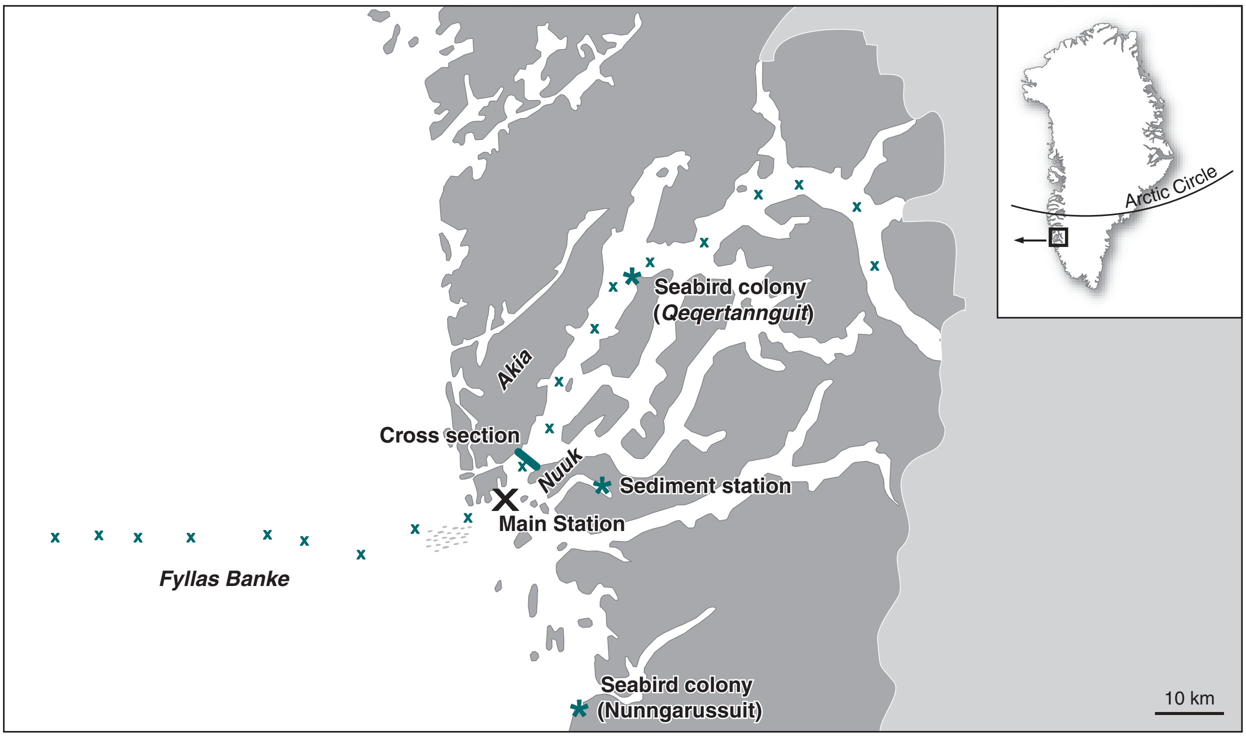
This report presents data from the sixth year of marine monitoring in Godthåbsfjord. The programme has established long time series of key parameters on physical, chemical and biological oceanography. Seasonal and annual samplings and monitoring are also conducted on sediment-water exchange rates, benthic plants and animals, seabirds and whales. The time series provide valuable information on seasonal and inter-annual patterns and variability, which are scarce or limited in Arctic regions. The programme also quantifies natural variability and aim to identify effects of climatic changes. A permanent station ('Main Station' (GF3); 64°07'N, 51°53'W) near the entrance to Godthåbsfjord forms the basis for monthly sampling. In addition, seasonal and annual sampling of different parameters at other selected stations and transects are carried out (figure 5.1). Sea ice conditions are also monitored locally within Godthåbsfjord using MODIS satellite imagery and a camera system overlooking a cross section of the outer part of the fjord. In addition, satellite images are also collected on the ice conditions within the Baffin Bay. Methods are briefly described throughout the report, for more details please consult the MarineBasis Nuuk Manual (www.nuuk-basic.dk).

5.1 Sea ice

Sea ice conditions in Baffin Bay are monitored daily using AMSR-E satellite images (3-6 km resolution, figure 5.2). Sea ice covered most of Baffin Bay and showed a maximum extent in late May, as observed in previous years. A retreat of sea ice was observed during spring/summer. Un-

Figure 5.1 Map of sampling stations in and around the Godthåbsfjord system. X represent sampling stations along the hydrographical length section.



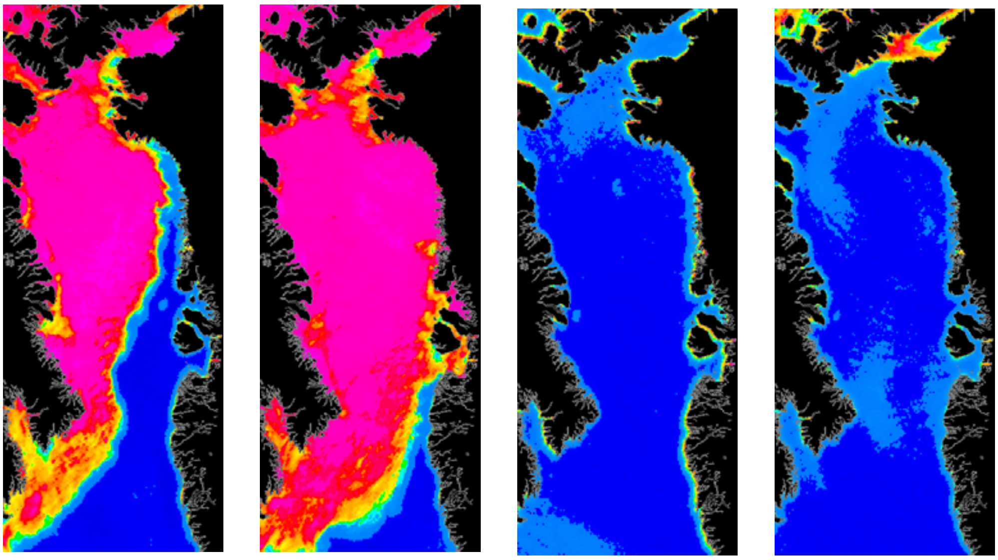


Figure 5.2 Satellite images (AQUA AMSR-E) showing sea ice extent in Baffin Bay in February, April, August and October 2011. Blue colour represents open water and pink and yellow colours represent different sea ice conditions.

Figure 5.3 Satellite images (AQUA-MODIS) showing sea ice conditions in Godthåbsfjord during January, April, August and October 2011.

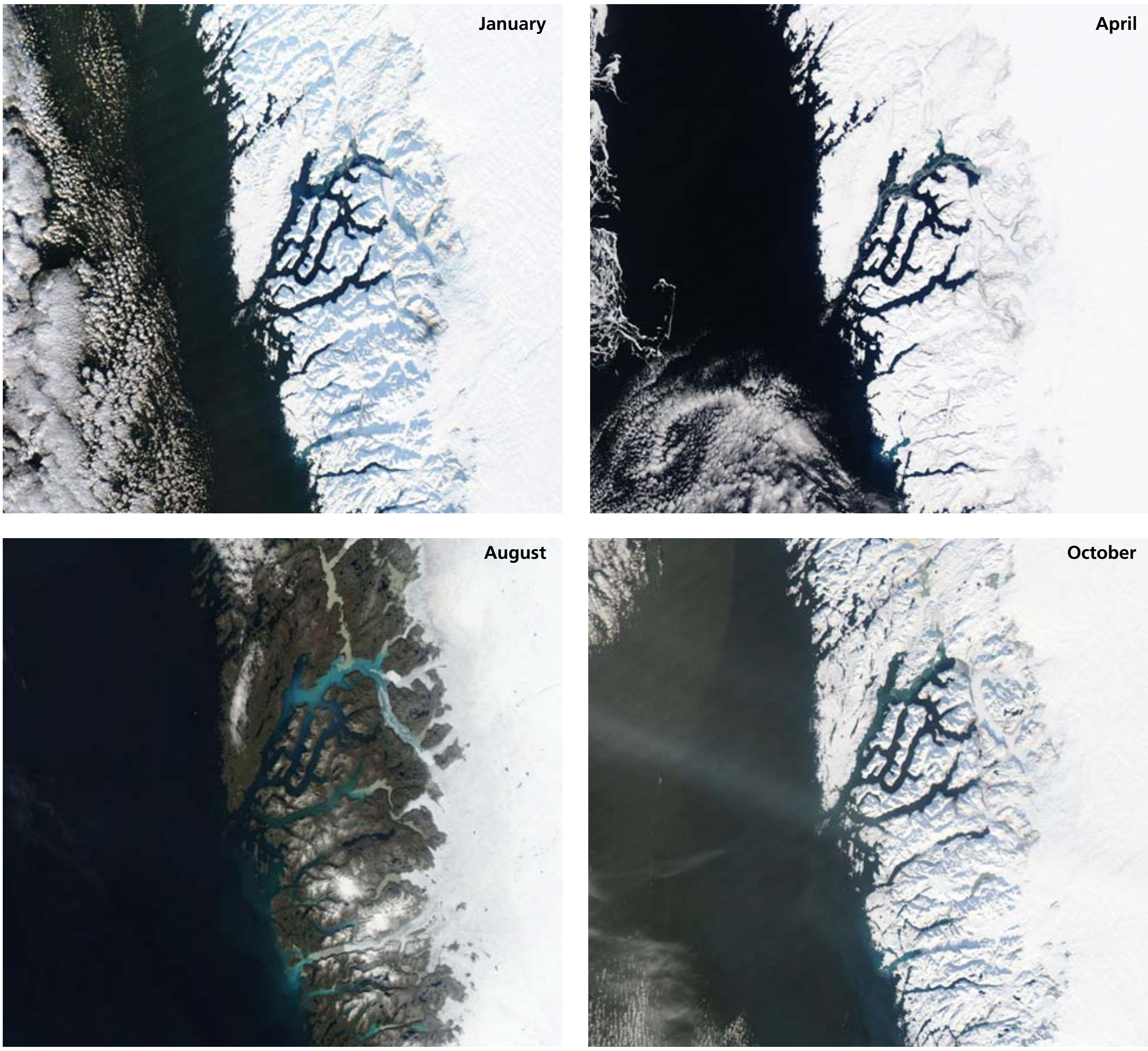


Figure 5.4 Digital images from Godthåbsfjord showing a burst of glacial ice in April and open water in July 2011.

fortunately, no images are available after early October; hence, the onset of sea ice build-up for the Baffin Bay is not included. However, it appears that the build-up of sea ice may have started late in 2011, as little ice is present in early October.

Satellite images (MODIS, 250 m resolution, figure 5.3) covering the entire Godthåbsfjord system are taken daily. Sea ice was mainly present in the innermost part of Godthåbsfjord and Kobbefjord. Analyses of satellite data on sea ice coverage are currently conducted in a collaboration between Greenland Institute of Natural Resources, the Danish Meteorological Institute and Greenland Climate Research Centre. As a courtesy, daily satellite images covering Greenland are available at www.dmi.dk. Ongoing research at the Greenland Climate Research Centre and the Danish Meteorological Institute are working on improving satellite imagery and remote sensing of the region.

Images recorded several times a day cover a cross section of Godthåbsfjord near the fjord entrance, close to Nuuk (figure 5.4). Export of glacial ice and sea ice from within the fjord generally occur in periodic bursts at different times of the year when sea ice does not hold back the glacial ice. One such burst took place in late April and the resulting ice and meltwater affected conditions locally within the plume (figure 5.4), as described in the following sections.

5.2 Length and cross sections

Hydrographical conditions are sampled annually along a cross and a length section of the fjord and monthly at the Main Station (GF 3). Vertical profiles of hydrographical parameters are carried out using a SBE19+ CTD profiler measuring salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence. The cross section from Nuuk to Akia showed a seaward export of fresher and warmer surface water concentrated primarily along the Akia side in mid-May (figure 5.5). This surface water also contained the highest concentrations of phytoplankton, as depicted by the high fluorescence values.

The annual length section from Fyllas Banke to the inner part of the fjord (approximately 200 km long) was conducted onboard 'R/V Adolf Jensen' in early May (figure 5.1). The warm saline water observed at depths outside Fyllas Banke, depicts the West Greenland Current (figure 5.6). Surface temperatures and salinities on top of Fyllas Banke extended into the outer part of the fjord. A fresher surface layer was found in the central and inner parts of the fjord while highest temperatures were found below this surface layer. The highest phytoplankton biomass (i.e. fluorescence) was found concentrated within the upper part of the water column across Fyllas Banke and within the fjord, while the biomass was rather homogenously distributed throughout the water

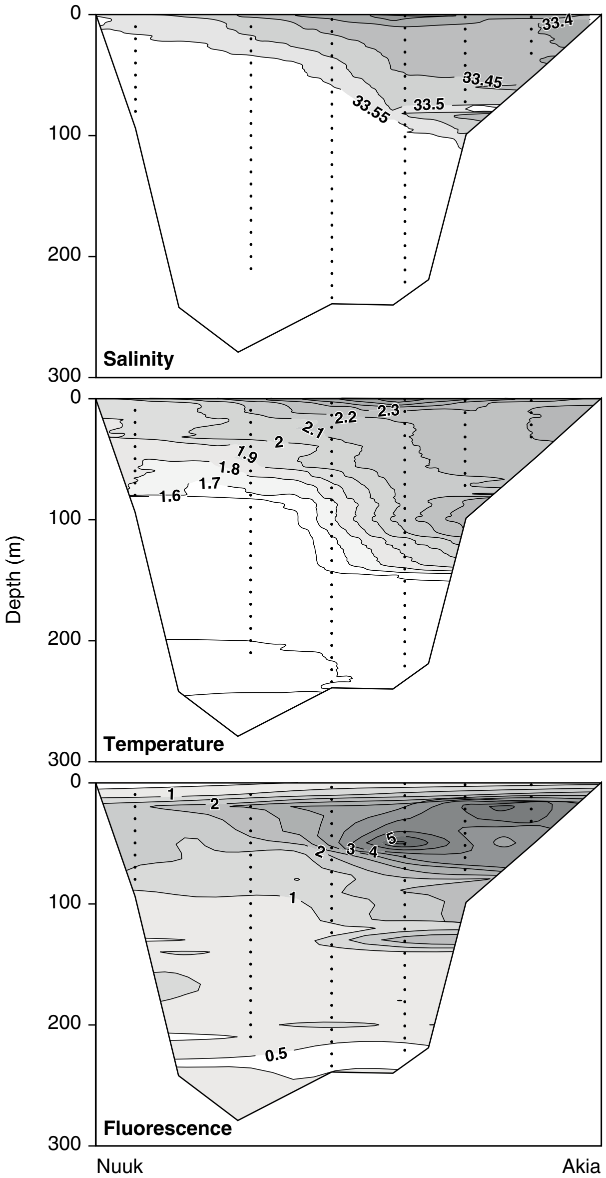


Figure 5.5 Salinity, temperature (°C) and fluorescence along the cross section from Nuuk to Akia in mid-May 2011. Vertical dotted lines represent sampling stations and depths in increments.

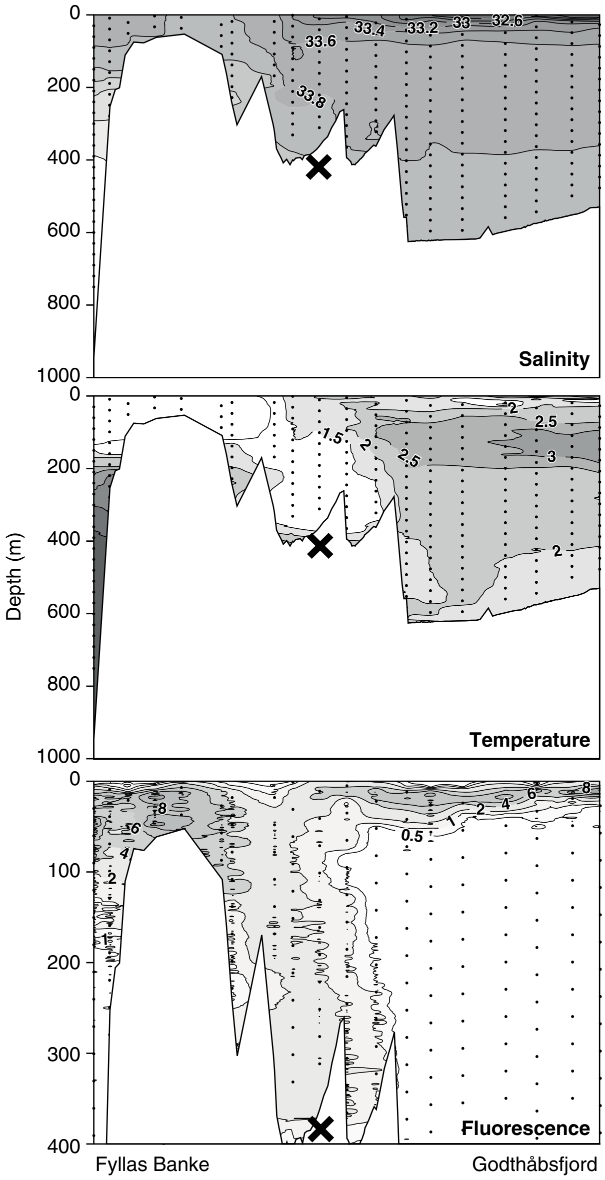


Figure 5.6 Salinity, temperature (°C) and fluorescence along the length section from Fyllas Banke to the inner part of Godthåbsfjord in early May 2010. Vertical dotted lines represent sampling stations and depths in increments. X marks the location of the 'Main Station'.

column at the fjord entrance due to tidal induced vertical mixing.

5.3 Pelagic sampling

The marine programme includes monthly sampling of abiotic and biotic parameters at the Main Station (GF3) near the fjord entrance (figure 5.1). Vertical profiles of salinity, temperature, density, oxygen concentration, turbidity, irradiance (PAR) and fluorescence were collected using a SBE19+ CTD profiler and water samples were analyzed for concentrations of pigments (chlorophyll *a* and phaeopigments) and nutrients (NO_x, PO_4^{3-}, SiO_4 and NH_4^+) at the standard depths 1, 5, 10, 15, 20, 30, 50, 100, 150, 250 and 300 m. In addition, dissolved inorganic carbon was measured in water samples from 1, 5, 10, 20, 30 and 40 m, representing the euphotic zone.

Particulate primary production was measured alongside vertical sinking flux of particulate material using short-term (approximately two hours) free-drifting mooring arrays. Primary production was measured using *in situ* C^{14} incubations corrected for *in situ* light conditions, while the vertical sinking flux of material was measured using particle interceptor traps deployed at 65 m. We measured the total amount of particulate material, pigments (chlorophyll *a* and phaeopigments) and particulate carbon and nitrogen in the collected material. Moreover, the monthly abundance and composition of phytoplankton and zooplankton was sampled using vertical hauls with 20 and 45 µm nets, respectively. Larger planktonic organisms, i.e. crab, shrimp and fish larvae, were sampled by oblique hauls using 335 µm bongo nets, this was also conducted along the length section in early May.

Abiotic parameters

The monthly hydrography profiles showed a moderate stratification of the water column during winter 2011 and warmer saltier water towards the bottom signifies an inflow of coastal waters (figure 5.7). Spring depicted a rather homogenous water column vertically mixed by tidal currents except for a confined event of stratification due to a burst of glacial ice and melt water in late April at the Main Station. Although this event was not strongly depicted in the hydrography, i.e. salinity and temperature, it was clear from the nutrients concentrations, phytoplankton biomass (i.e. chlorophyll *a*) and production, as described later. Similar to previous years, outflow of melt water along with atmospheric heat exchange and solar heating of the surface layer resulted in a stratification withstanding tidal mixing during summer. Autumn conditions, i.e. reduced melt water and atmospheric heat exchange, weakened the stratification of the upper water column making it homogenous and with signs of inflow of coastal water in the lower water column during the last months of the year. The light regime of the upper water column varied due to seasonal variations in incoming irradiance and absorption by suspended material in the water (e.g. phytoplankton). Irradiance remained below 5 µmol photos m^{-2} s^{-1} at depths below 50 m.

Winter mixing of the water column along with inflow of nutrient rich warm saline coastal water replenished the nutri-

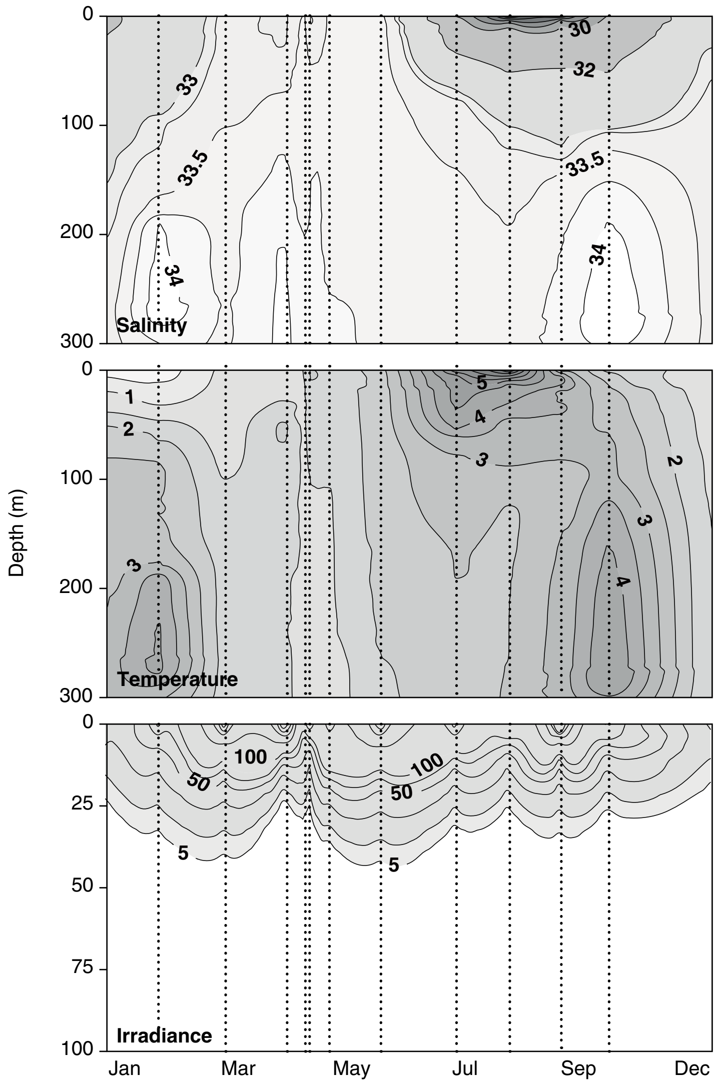
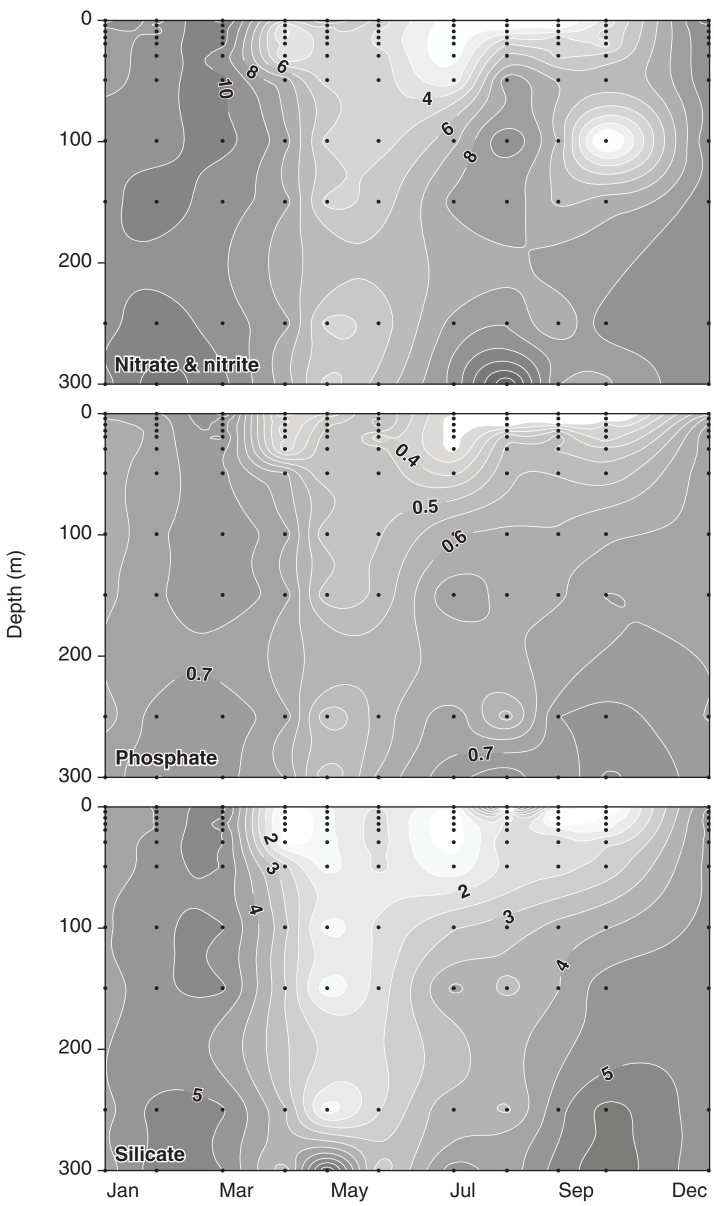


Figure 5.7 Annual variation in salinity, temperature (°C) and irradiance (PAR) at the 'Main Station' in 2011. Vertical dotted lines represent sampling days and depths in increments.

ent load in the upper part of the water column (figure 5.8). The early observation of a phytoplankton bloom within the upper water column in late April, as described later, quickly depleted nutrients within the surface layer. Though not clearly visible from the hydrography, i.e. temperature and salinity, a weak stratification of the upper part of the water column was present during late April as observed in nutrient and pigment profiles (figure 5.8 and 5.9). Subsequently, nutrients levels remained low throughout much of the water column later in spring due to vertical mixing at the fjord entrance, while the summer stratification further limited the low nutrients concentrations to the surface layer. Autumn conditions weakened the stratification and vertical mixing re-established nutrient levels in the surface layer.

Figure 5.8 Annual variation in nitrate and nitrite (μM), phosphate (μM) and silicate (μM) concentrations at the 'Main Station' in 2011. Vertical dotted lines represent sampling days and depths.



Biotic parameters

The phytoplankton biomass, i.e. chlorophyll *a* concentrations, remained low during winter as it was observed in previous years (figure 5.9). However, it is worth noticing that the timing, intensity and species composition of the spring phytoplankton bloom differs considerably from what was observed in previous years. In April 2011, high pigment concentrations was observed in the upper 30 m with concentrations of chlorophyll *a* >7.5 μg l^{-1} and phaeopigments >2.4 μg l^{-1}. This bloom was maintained in the upper part of the water column due to a weak stratification likely caused by melting of glacial ice from the inner Godthåbsfjord, as suggested above. Below the pycnocline (50-300 m) the bloom was dispersed though concentrations were still high compared to previous years (chlorophyll *a* and phaeopigments >1.4 and >0.7 μg l^{-1}, respectively). In May, pigments have decreased (chlorophyll and phaeopigments <2 and <1.4 μg l^{-1}, respectively) and the bloom was dispersed throughout the water column. Concentrations were low in June. The following stratification of the water column, due to freshwater outflow, atmospheric heat exchange and solar heating from July, maintained the bulk phytoplankton biomass within the euphotic zone (upper 30 m) until October resulting in maximum pigment concentrations of chlorophyll *a* and phaeopigments 4.8 and 1.7 μg l^{-1}, respectively, at 5 m depth in September.

The primary production measurements showed a pronounced spring production peak in April (1743 mg C m^{-2} d^{-1}), the highest production value measured during the entire time series (figure 5.9). Hereafter primary production decreased in May and June. Unfortunately the mooring with incubated primary production experiment was lost during the sampling campaign in July, though the productivity in August, September and October resembles the high productivity of secondary phytoplankton blooms in previous years (414, 260 and 177 mg C m^{-2} d^{-1}, respectively). The high primary production throughout the productive period resulted in the highest measured integrated annual primary production during the time series 139 g C m^{-2} y^{-1}.

The plankton community

Vertical net hauls (20 μm) from 0-60 m was used to sample phytoplankton species composition. The phytoplankton commu-

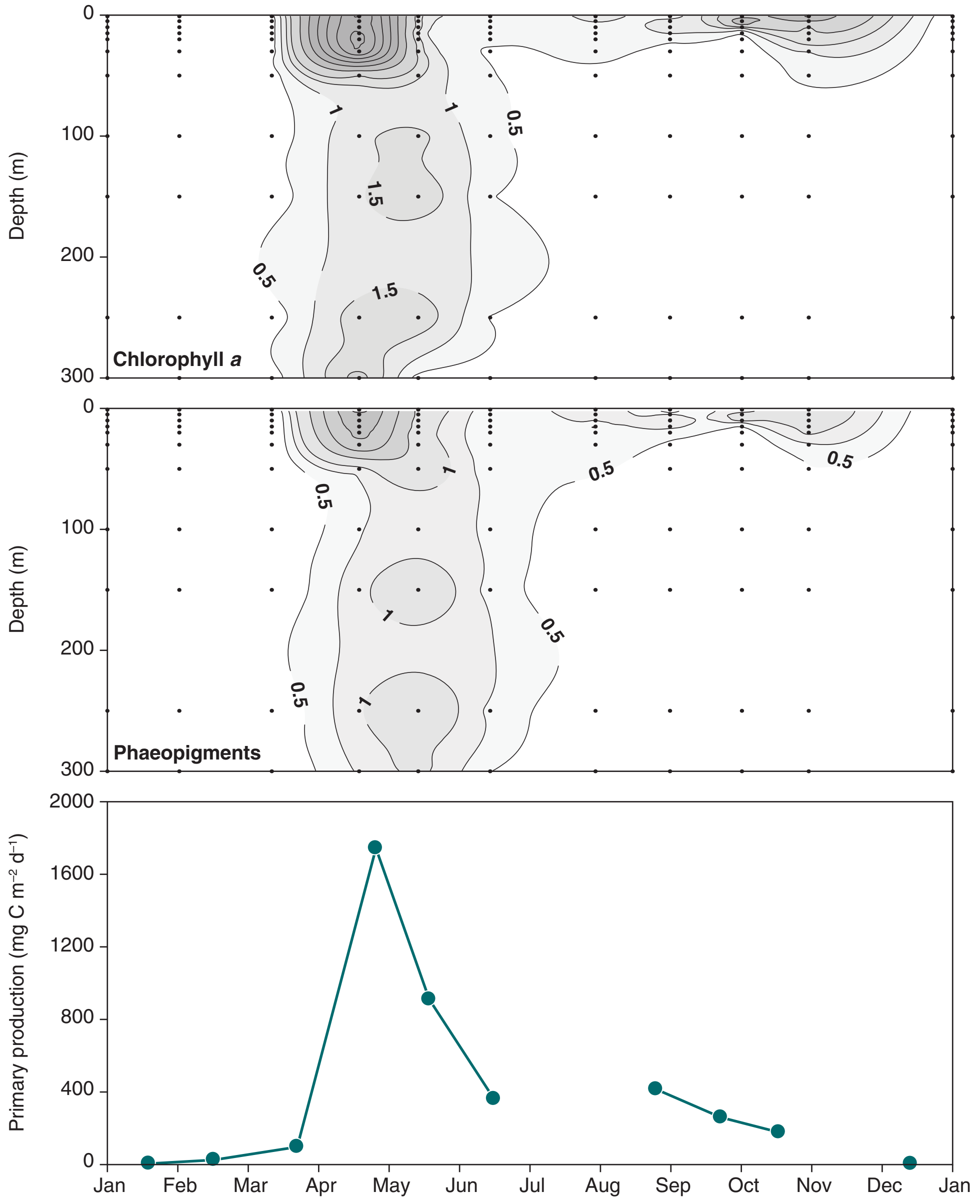


Figure 5.9 Annual variation in chlorophyll a *concentration (µg l⁻¹), phaeopigments concentration (µg l⁻¹) and primary production (mg C m⁻² d⁻¹) at the 'Main Station' in 2011. Vertical dotted lines on chlorophyll a and phaeopigments plots represent sampling days and depths.*

nity showed the characteristic pattern with diatoms dominating in winter, additionally diatoms was surprisingly dominating during the spring bloom in April and May (figure 5.10). In previous years, the spring bloom was dominated by *Phaeocystis* sp. (*Haptophyceae*). Only 2009 differed from this general observation, where *Phaeocystis* sp. remained absent throughout the year. *Phaeocystis* sp. (*Haptophyceae*) became dominating in June, a month later than observed in previous years. Unfortunately the sample of July 2011 was lost but later samples showed an autumn bloom dominated by diatoms (figure 5.10) mainly *Thalassiosira* sp. resembling previous years. Overall, more than half of the phytoplankton community integrated during 2011 was comprised of the algae group *Chaetoceros* spp., due to the dominance of this species in the spring phytoplankton bloom in April (table 5.1). *Thalassiosira* spp. and *Phaeocystis* sp. comprised 16.7 and 11.2% of the phytoplankton community integrated whereas other species and groups comprised <5%.

Vertical zooplankton net hauls (45 µm WP2 net) were conducted from 0-100 m. Abundances of both copepods and other zooplankton groups were in general low in 2011 compared to previous years. The copepod community was dominated by *Microsetella norvegica*, though in the spring *Oncaea* sp. contributed significantly to the copepod community whereas *Calanus* spp. comprised <12% in May and June (figure 5.11). Abundances of other zooplankton groups increased in April, especially bivalve larvae (data not shown). In July, zooplankton abundances were surprisingly low for both copepods and other

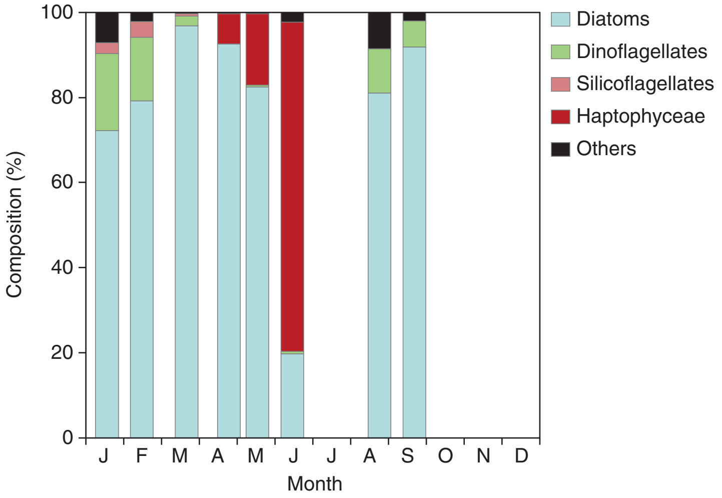


Figure 5.10 Seasonal variation in phytoplankton community composition (%) at the 'Main Station' during 2011.

Table 5.1 The ten most dominant phytoplankton species integrated over the year as their relative accumulated proportion of total cell counts (%) at the 'Main Station' in 2011.

2011	
Chaetoceros spp.	55.4
Thalassiosira spp.	72.1
Phaeocystis sp.	83.3
Thalassionema nitzschioides	87.6
Fragilariopsis spp.	90.6
Protoperidinium sp.	91.8
Dinobryon baltica	92.9
Centric diatoms not det.	93.6
Eucampia groenlandica	94.4
Navicula sp.	95

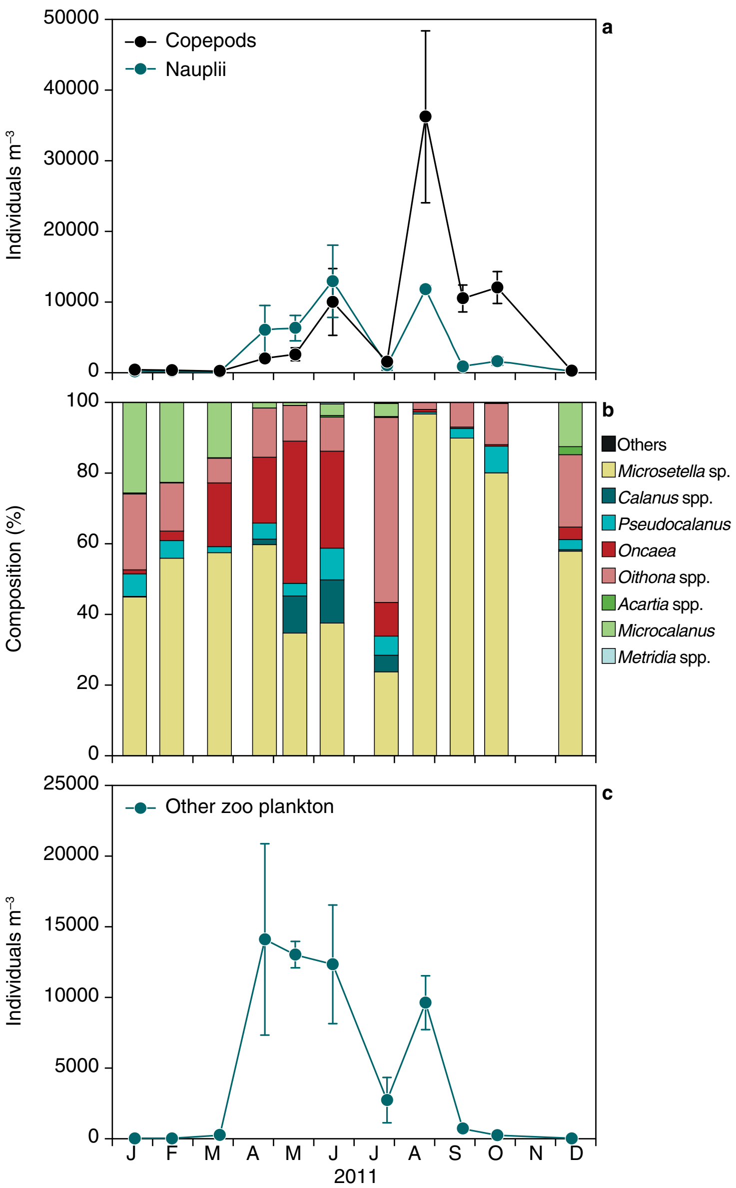


Figure 5.11 a) Annual variation in abundance (individuals m^{-3}) of copepod nauplii and copepods (i.e. copepodites and adult stages) b), copepod community composition (%) and c) abundance of other zooplankton groups (individuals m^{-3}) at the 'Main Station' in 2011. Error bars represent standard deviation.

zooplankton groups. However, it is worth noticing that the species composition differed significantly in this month from what was observed in previous years. The copepod community was dominated by *Oithona* spp. (52 %) whereas *Microsetella norvegica*, which has been dominating in previous years, only comprised <24 % of the total copepod community. In the same sample, abundances of rotifers were low compared to previous years. The copepod abundance peaked in August, and despite abundances was significantly lower than in previous years, the species composition was comparable to previous years with dominance of *Microsetella norvegica* (96 % of total copepod abundance).

Since the beginning of the annual sampling at the Main Station (GF3) in 2008, the abundance of fish larvae has varied over the years and has a temporal shift in species composition during summer (figure 5.12). In 2008, sand eel *Ammodytes* sp. and Arctic shanny *Stichaeus punctatus* larvae dominated the abundance in spring followed by capelin *Mallotus villosus* dominating the abundance in late summer/autumn. The abundance of sand eel larvae was very high in spring 2006 and 2007 with concentrations as high as 25 individuals 100 m^{-3}. Since 2008, however sand eel larvae have almost disappeared in the samples whereas capelin and Arctic shanny larvae were caught in 2009 and 2011. Atlantic cod *Gadus morhua* larvae and especially American plaice *Hippoglossoides platessoides* larvae increased in abundance in 2011 with the highest abundance seen in the time series in June 2011. Overall 2010 was a year with very low abundance of fish larvae in all month.

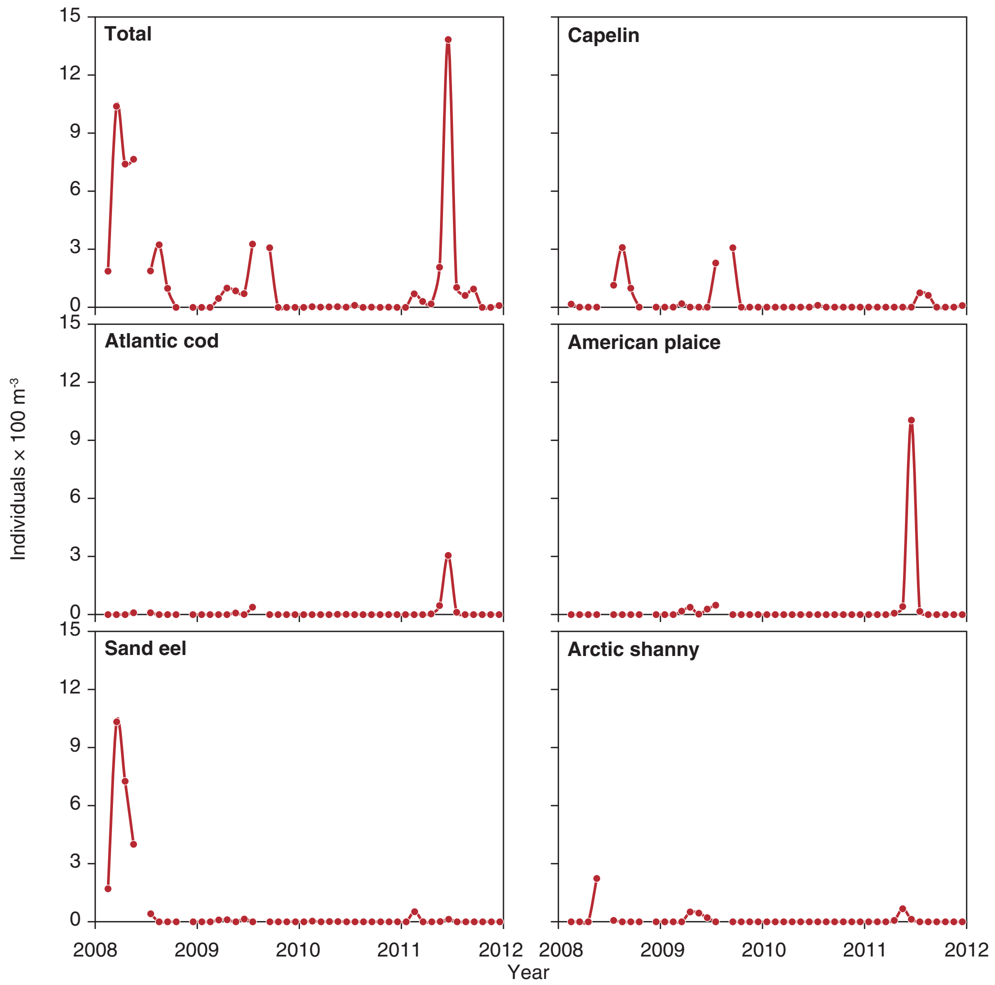


Figure 5.12 Annual variation in abundance of fish larvae in total, capelin, Atlantic cod, American plaice, sand eel and Arctic shanny from 2008 to 2011 at the Main Station (GF3). Samples were collected each month except January, June and November 2008 and August 2009.

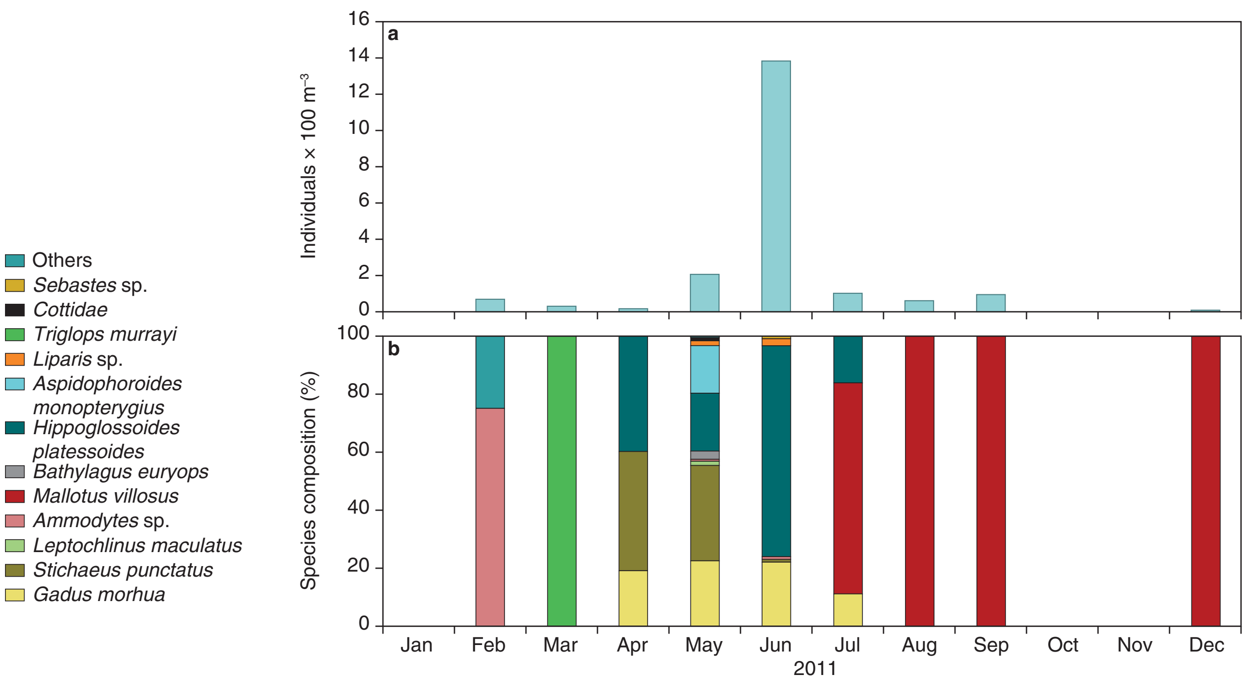


Figure 5.13 Annual variation in abundance (individuals per 100 m³) (a) and community composition (%) (b) of fish larvae at the Main Station (GF3) in 2011.

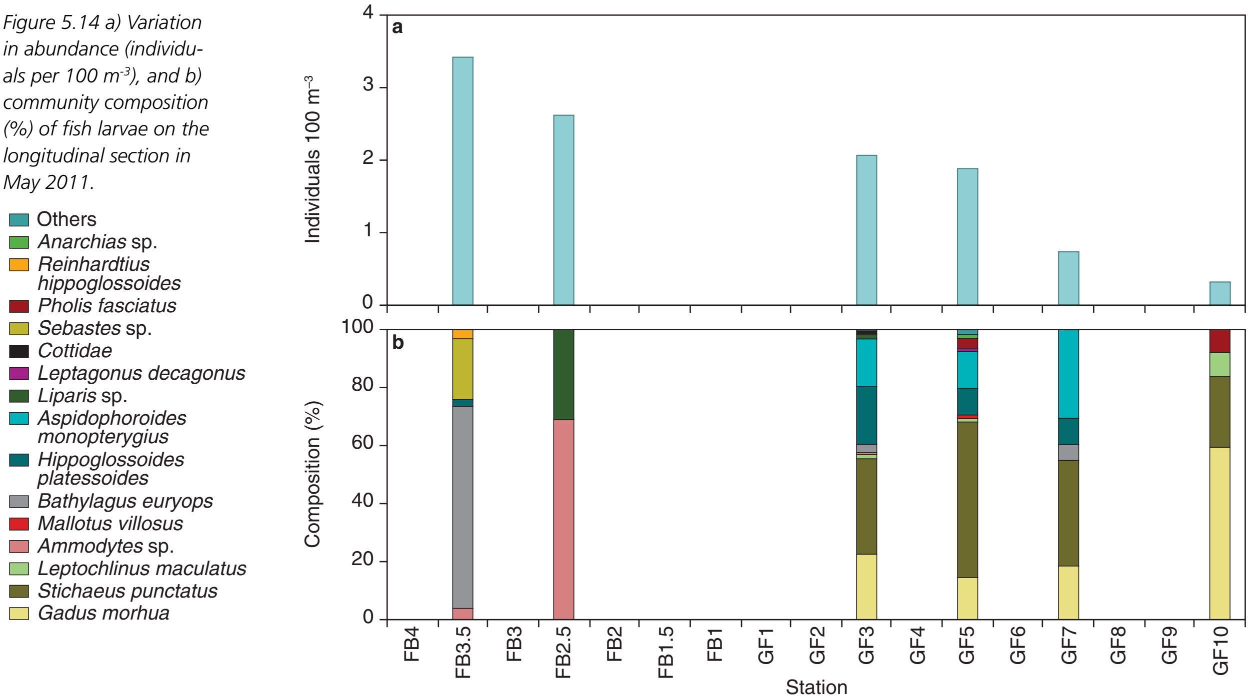


Figure 5.14 a) Variation in abundance (individuals per 100 m^{-3}), and b) community composition (%) of fish larvae on the longitudinal section in May 2011.

In 2011, the highest concentration of fish larvae was found in June (figure 5.13a), where American plaice larvae accounted for 73 % of the total abundance (figure 5.13b). American plaice and Atlantic cod larvae were caught from April to July, and capelin was caught from July to September and again in December. Only capelin was caught in August, September and December. Most species were caught in May.

The length section in the fjord in May showed a different pattern in fish larvae abundance and species composition compared to previous years. In 2011, highest abundance was found on Fyllas Banke (FB2.5 and FB3.5, figure 5.14a). From 2008 until 2010, highest abundances were found closer to the inlet of the fjord at the Main Station. In 2006 and 2007, however, abundance on Fyllas Banke was very high due to sand eel larvae (112 and 35 individuals 100 m^{-3} in 2006 and 2007, respectively, at station FB2.5). In 2011, sand eel larvae accounted for 69 % of the total abundance on the top of Fyllas Banke (FB2.5) whereas Goiter blacksmelt *Bathylagus euryops* larvae accounted for 70 % of the total abundance on the slope of Fyllas Banke (FB3.5, figure 5.14b). Redfish *Sebastes* sp. and a single Greenlandic halibut *Reinhardtius hippoglossoides* larva were found on the slope of Fyllas Banke (FB3.5).

Species composition varied along the length section with fewer species in the samples from Fyllas Banke and from deeper inside the fjord (figure 5.14b). Arctic shanny and Atlantic cod larvae were only found in the fjord, but on all stations (GF3-GF10). Atlantic cod larvae accounted for 60 % of the total abundance deepest inside the fjord (GF10).

Fish larvae species composition seems to vary between years with most species found in 2011 (table 5.2).

To assess shellfish abundance as well as fish larvae abundance at the Main Station (GF3), single oblique sampling with a bongo net (335 µm) was used each month during 2008 (except June), 2009 (except October) and 2010-2011. Additional samplings with a double oblique bongo net (335 and 500 µm) were carried out along a length section from offshore Fyllas Banke to the inner part of the fjord from 2006 to 2011. Thirteen stations were sampled in May 2006, four stations in 2007 and 2008, three stations in 2009, five stations in 2010 and six stations in 2011.

The shellfish community at the Main Station (GF3) showed the characteristic pattern with peak abundance of *Pandalus* sp. in April, and of *Chionoecetes opilio* and *Hyas sp*. in May (figure 5.15). Density of *Pandalus* sp. were significantly lower in 2011 compared to 2010, but at the same level as observed in 2009. Density of *Chionoecetes opilio* was low and consistent with observations in previous years; whereas density of *Hyas* sp. has continued the increasing trend from 0.05 individuals m^{-3} in

Table 5.2 Species list of fish larvae 2006-2011.

Species list	2006	2007	2008	2009	2010	2011
Gadus morhua	×	×	×	×	×	×
Stichaeus punctatus	×	×	×	×	×	×
Leptochlinus maculatus	×	×	×	×	×	×
Ammodytes sp.	×	×	×	×	×	×
Mallotus villosus		×	×	×	×	×
Aspidophoroides monopterygius	×	×	×			×
Bathylagus euryops		×	×	×	×	×
Cyclothone sp.		×				
Liparis sp.		×				×
Liparis gibbus					×	
Pholis sp.	×	×	×			
Pholis fasciatus					×	×
Reinhardtius hippoglossoides	×		×			×
Myoxocephalus scorpius			×		×	
Hippoglossoides platessoides			×	×	×	×
Sebastes sp.			×			×
Gadus ogac			×	×	×	
Leptagonus decagonus				×	×	×
Agonidae				×		
Lumpenus lampretaeformis				×	×	
Triglops murrayi						×
Cottidae						×
Anarchias sp.						×
Total	**7**	**10**	**13**	**11**	**13**	**16**

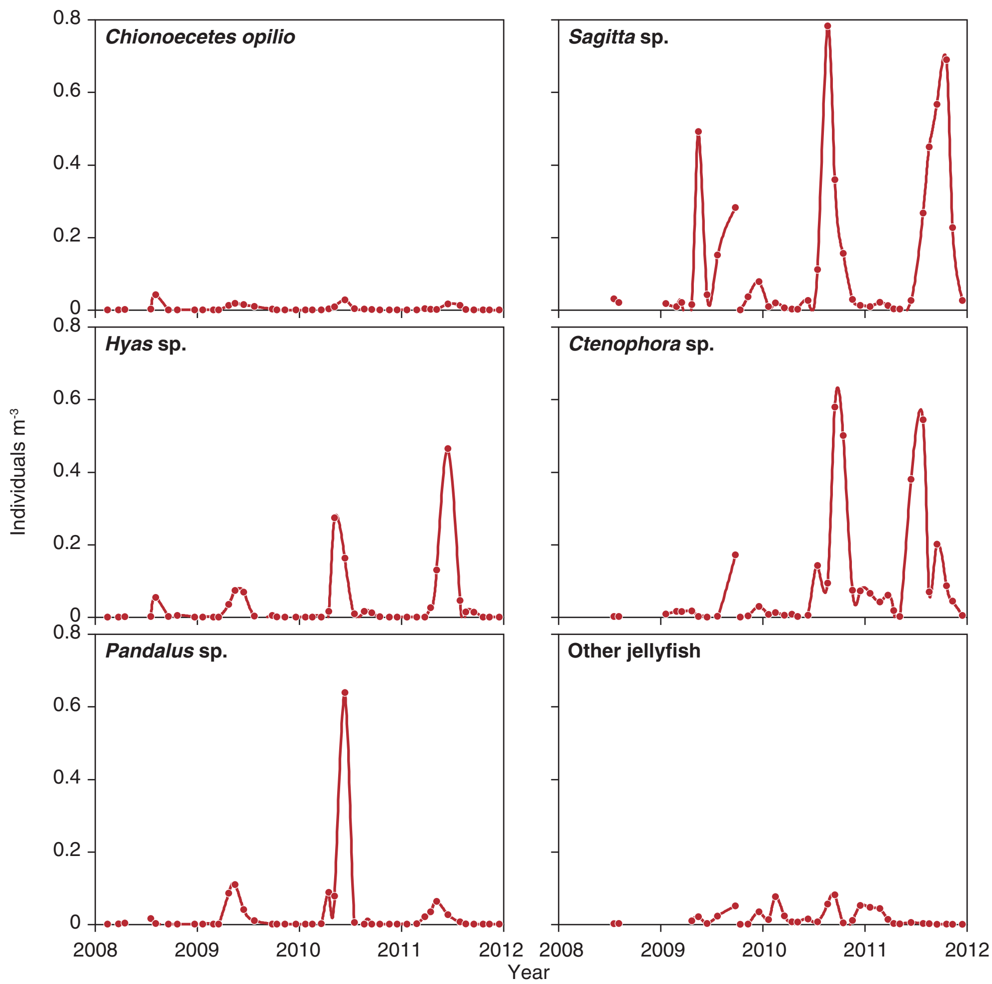


Figure 5.15 Annual variation in abundance (individuals m^{-3}) of Chionoecetes opilio, Hyas sp., Pandalus sp. Sagitta sp., Ctenophora sp. and other jellyfish at the Main Station (GF3) from 2008 to 2011. Samples were collected each month except November 2008 and August 2009.

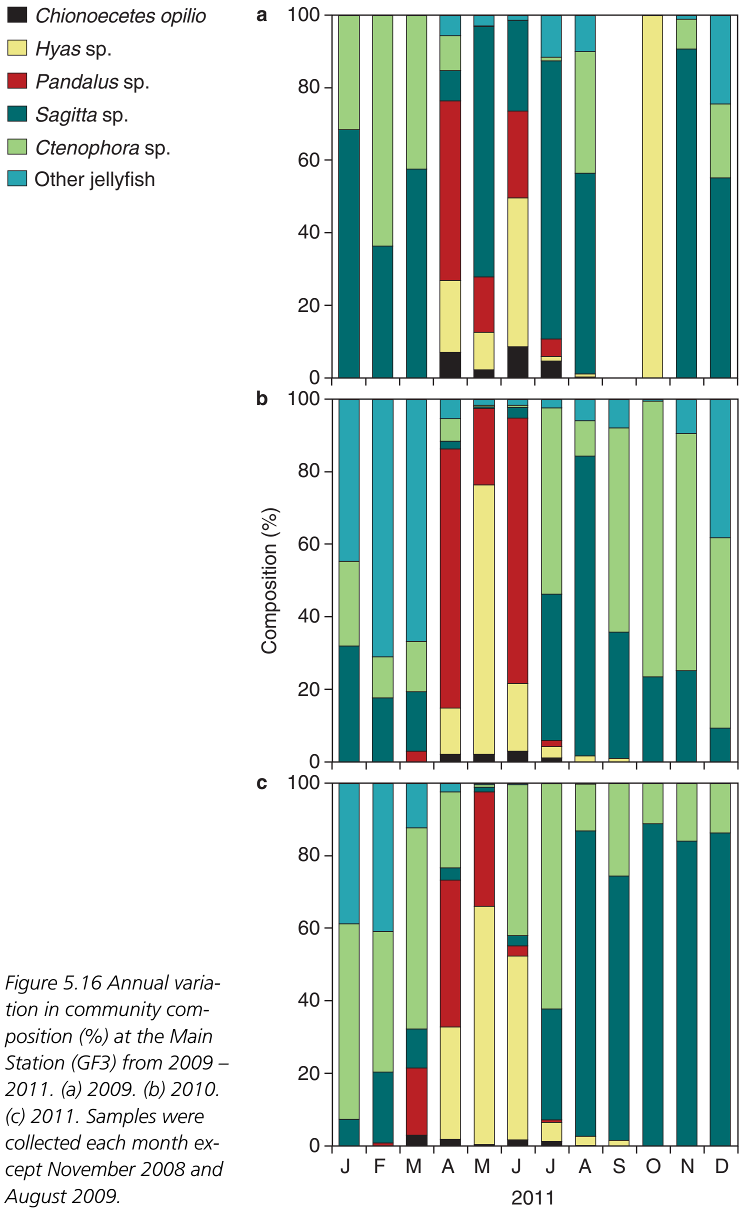


Figure 5.16 Annual variation in community composition (%) at the Main Station (GF3) from 2009 – 2011. (a) 2009. (b) 2010. (c) 2011. Samples were collected each month except November 2008 and August 2009.

2008 to 0.46 individuals m^{-3} in 2011 (figure 5.16). Larvae stage zoae I of *C. opilio* and *Hyas* sp. dominated samples in April to June whereas larvae stage zoae II were more prevalent in July. Low concentrations of megalope stage of *C. opilio* and *Hyas* sp. were observed in October. Throughout the time series, the abundance of *C. opilio* has been low compared to *Hyas* sp. and *Pandalus* sp.

At the Main Station (GF3), *Sagitta* sp. dominated the community from August to December, whereas *Ctenophora* sp. and jellyfish were dominating from January to March (figure 5.15). *Sagitta* sp. has been recorded in considerably higher numbers the past two years (peaked at 0.8 individuals m^{-3} in August 2010 and 0.7 individuals m^{-3} in October 2011). Another consistently abundant species was *Ctenophora* sp. (39 to 55 % from January to March and 62 % in July) while jellyfish were less abundant compared to previous years and only observed at the Main Station from January to April.

Along the length section from Fyllas Banke (offshore) to the inner part of the fjord (GF10) concentrations of crab larvae (*Hyas* sp.) and shrimp larvae (*Pandalus* sp) were low compared to 2010 and only very few larvae of the commercial species *Chionoecetes opilio* were recorded at the offshore station FB2.5 (0.002 individuals m^{-3}) (figure 5.17). Both *Hyas* sp. and shrimp larvae are to be found at almost all stations along the fjord transect, with variations in density among species and between stations. Highest numbers of individuals m^{-3} were observed in 2006 followed by a sharp decline in 2007 to 2009. Relatively high numbers of *Hyas* sp. and shrimp larvae were recorded in 2010 but declined significantly in 2011 to levels comparable with observations from 2008.

Along the length transect, the community composition differed not only between stations but also between years (figure 5.18). In 2010 and 2011, larvae of *Chionoecetes opilio* were far more abundant at the offshore station FB3.5 compared to the other stations along the length transect. Where *Hyas* sp. dominates the community at the shallow parts of Fyllas Banke (FB2.5) and at GF3, *Pandalus* sp. was in 2011 dominant at station GF10, located at the inner part of the fjord. *Sagitta* sp. was absent or recorded at low numbers at the outer stations from FB3.5 to GF3, but abundant at the inner stations, and dominating the community at GF7. Larvae of *Ctenophores* and jellyfish were observed in low numbers at the two inner stations (GF7 and GF10) and at the FB3.5, respectively.

Vertical sinking flux

Particulate material sinking from the euphotic zone (i.e. upper 65 m) was measured using free-drifting short-term (approximately two hours) sediment traps, and the collected material were quantified and analysed. Low sinking fluxes of both total particulate carbon (TPC) and chlorophyll a (Chl *a*) were observed during winter, while the early phytoplankton bloom in late April induced high sinking fluxes (figure 5.19). The September peak in TPC sinking flux corresponds with a burst in ice from the

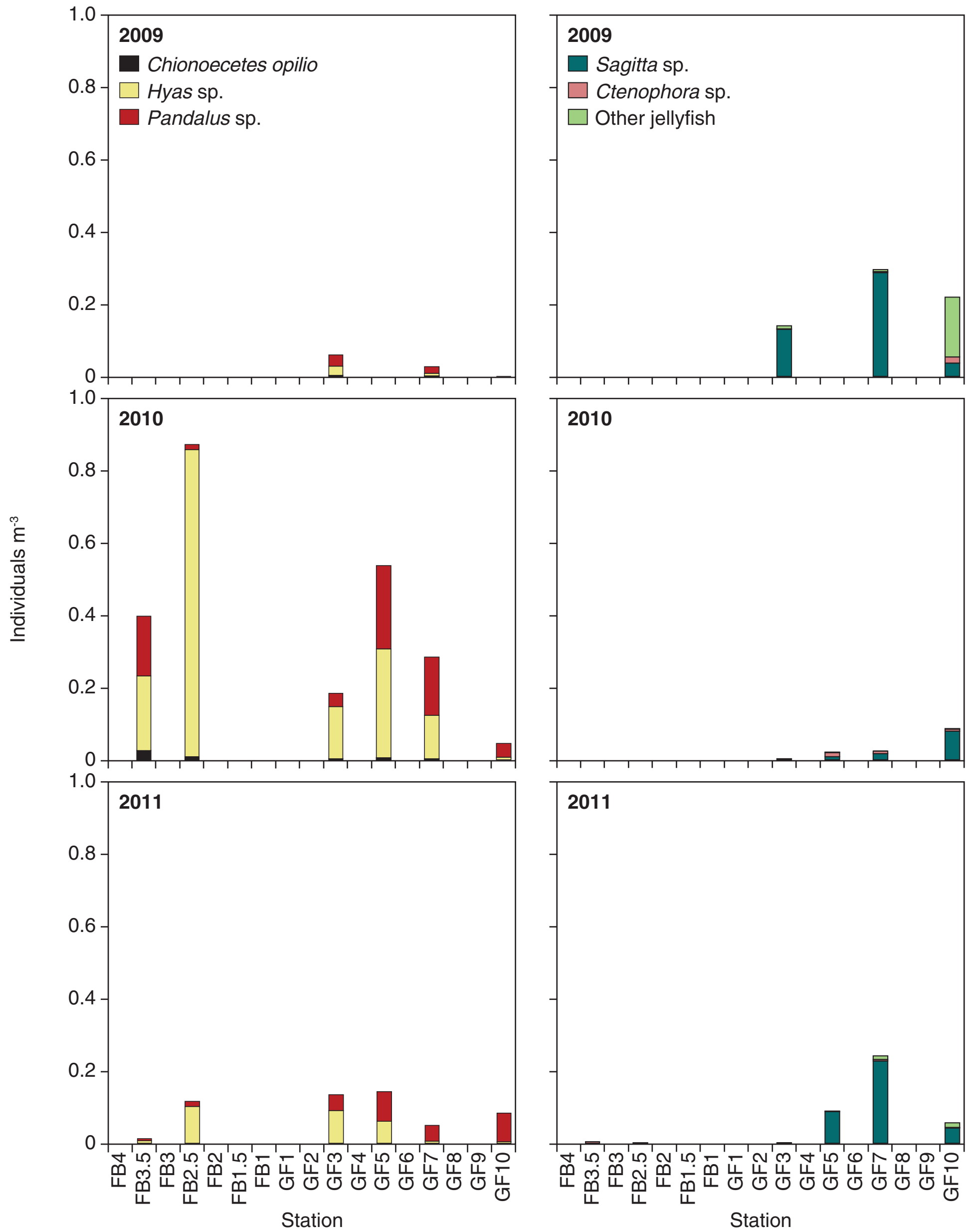


Figure 5.17 Annual variations in abundance (individuals m^{-3}) of Chionoecetes opilio, Hyas sp., Pandalus sp. Sagitta sp., Ctenophora sp. and other jellyfish along the length section from Fyllas Banke (offshore) to the inner part of Godthåbsfjord conducted in May 2009 to 2011. In 2009, no sampling was carried out at Fyllas Banke.

inner part of the fjord (data not shown), while the October peak in Chl a corresponds with a fall phytoplankton bloom (see figure 5.19). High C:N ratios during winter indicate a high content of refractory or lithogenic material, while the lower ratios during spring and summer support a higher contribution of fresher algal material. This is further supported by the higher (i.e. less negative) $\delta^{13}C$ and lower $\delta^{15}N$ values during spring and summer, when fresh algal material is more abundant. The annually integrated TPC sinking flux (351.6 g C m^{-2} y^{-1}) was similar to 2010 (351. 2 g C m^{-2} y^{-1}) and also comparable to values from 2006-09 (between 253.9 and 431.5 g C m^{-2} y^{-1}).

5.4 Sediments

Organic material reaching the sediments is fuelling the benthic communities, and being mineralized through a number of processes. At the sediment surface, oxygen is the key electron acceptor while sulphate is the key acceptor below the oxidized zone. This process leads to direct or indirect oxygen consumption, therefore the rate of organic matter remineralisation may be estimated by measuring the flux of oxygen into the sediment.

The monitoring work included sediment core sampling during May, August and November in 2011 at a permanent sampling station in Kobbefjord (Sediment

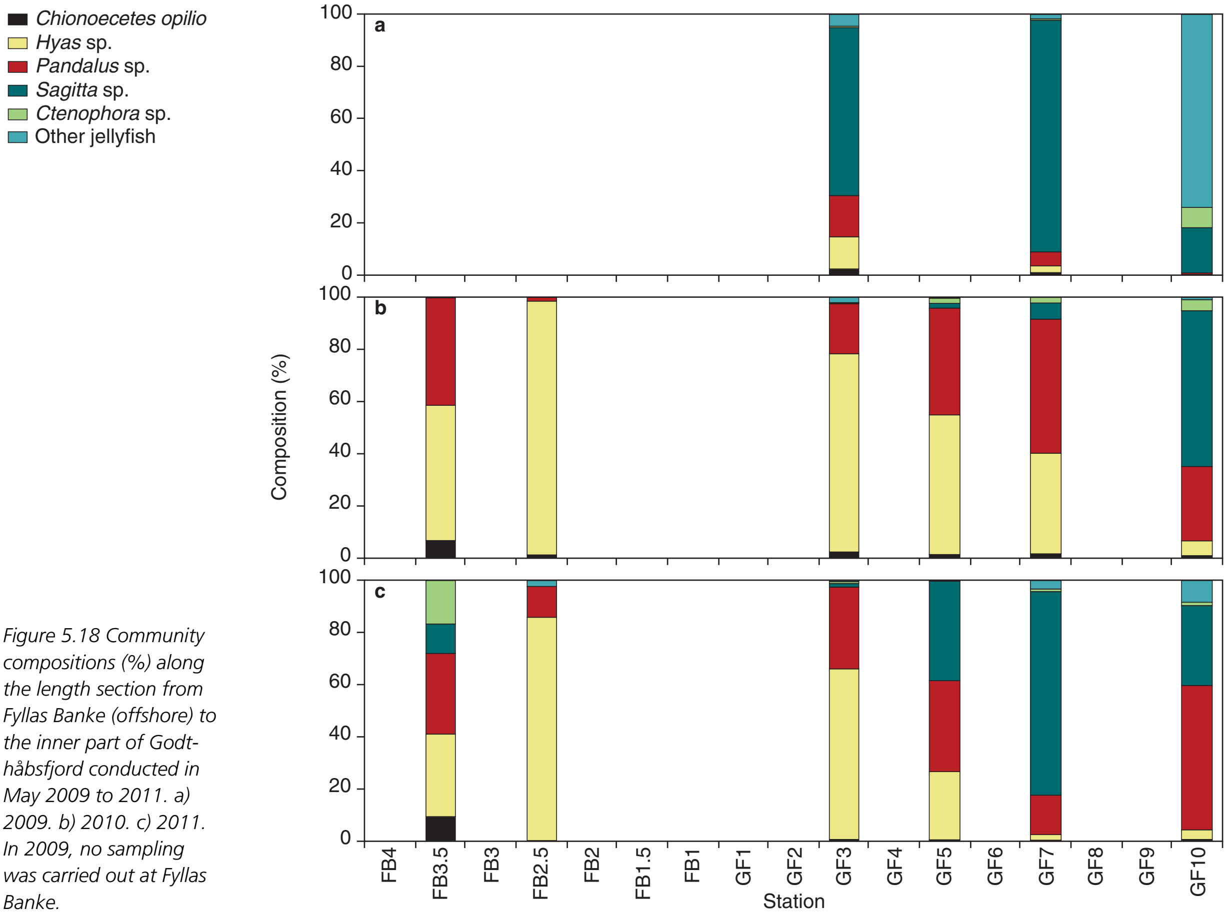


Figure 5.18 Community compositions (%) along the length section from Fyllas Banke (offshore) to the inner part of Godthåbsfjord conducted in May 2009 to 2011. a) 2009. b) 2010. c) 2011. In 2009, no sampling was carried out at Fyllas Banke.

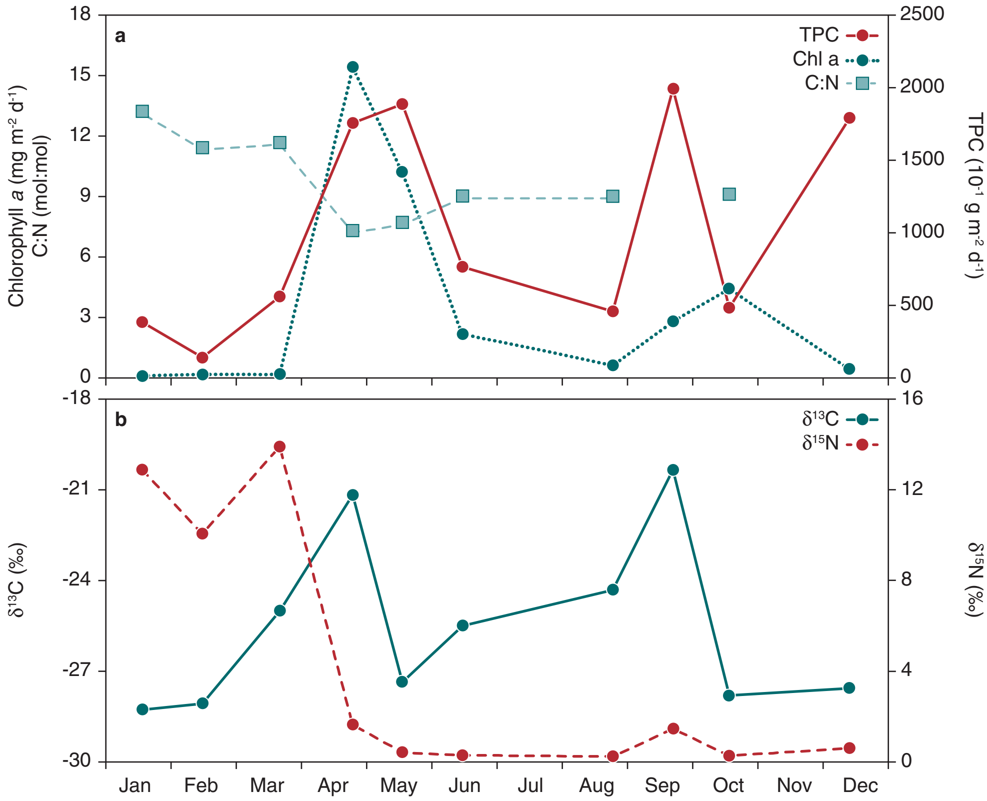


Figure 5.19 a) Annual variation in vertical sinking flux of total particulate carbon (mg m^{-2} d^{-1}), chlorophyll a (mg m^{-2} d^{-1}) and the carbon to nitrogen ratio (mol:mol) b), $\delta^{13}C$ (‰) and $\delta^{15}N$ (‰) of the sinking particulate material c) collected at the Main Station in 2011.

Station; figure 5.1). Closed incubations and microprofiling were used to measure oxygen fluxes. As observed in previous years the oxic zone was limited to the top 1 cm of the sediment throughout the year (figure 5.20). The highest oxygen consumption occurred in August, although comparable levels were observed in May and November (figure 5.21). The total oxygen uptake rates (TOU) are among the highest values measured since early in the time series (2005-06). The measured TOU rates were also high compared to the diffusive oxygen uptake (DOU), particularly during August and November, suggesting a high faunal activity within the sediment. Unfortunately, due to technical problems, DIC exchange across the water-sediment interface was not analyzed in time for the present report.

5.5 Benthic fauna and flora

Benthic fauna

Sea urchin *Strongylocentrotus* sp. and scallop *Chlamys islandica* are dominant species in the shallow parts (0-75 m) of Kobbefjord. The physiological status of both species is monitored each year during spring at the entrance of the fjord at 50-60 m depth. This is done by calculation of a condition and gonad index for both species (figure 5.22). The aim is to develop a time series of the energetic condition for these benthic species and to document potential temporal trends. Both species spawn in late spring/early summer and thus gonad biomass of both species should approach the seasonal maximum when sampled. For sea urchins, the gonad index for 2011 is the

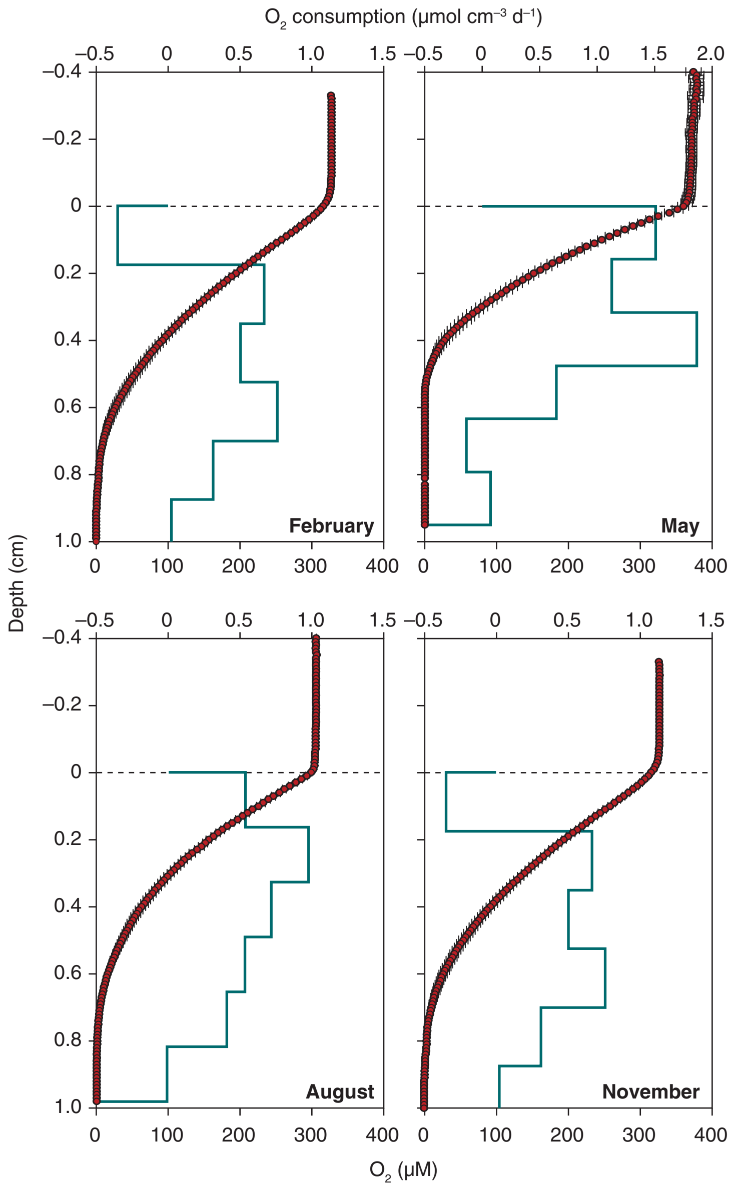


Figure 5.20 Vertical concentration profiles of oxygen (closed dots) and modelled consumption rates (solid line) from microelectrode profiles with sediment depth for each of the four sampling periods. Error bars represent standard error of the mean.

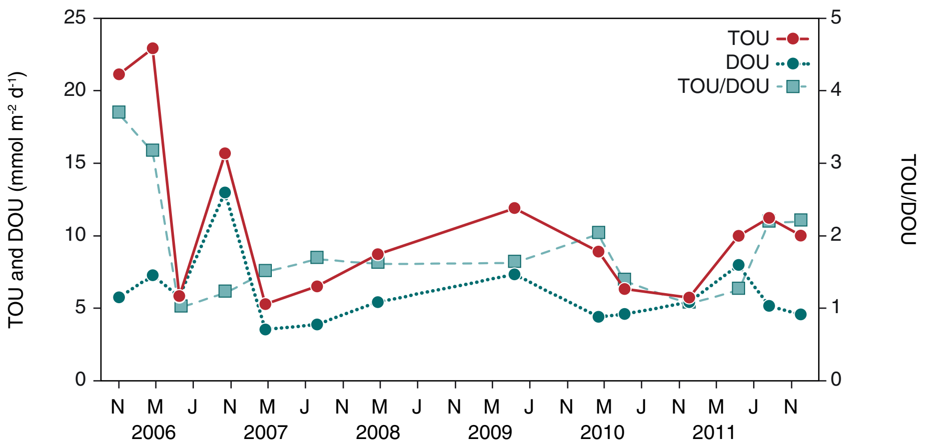


Figure 5.21 Variation in total oxygen uptake (TOU) and diffusive oxygen uptake (DOU) (mmol m-2 d-1) and in the TOU/DOU ratio from 2005-11.

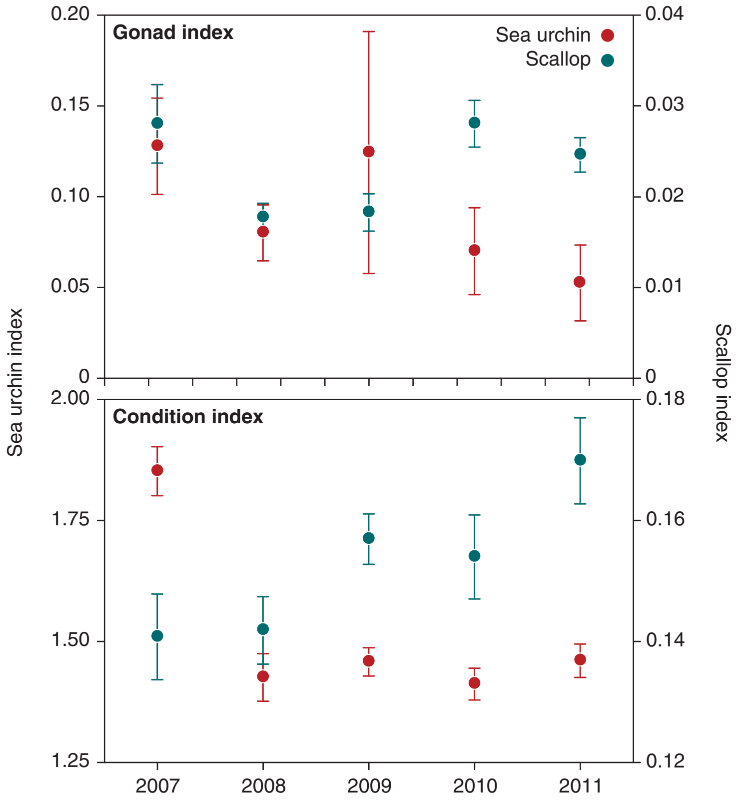


Figure 5.22 Gonad and condition index (mean ± 95% CI) for the scallop Chlamys islandica *and the sea urchin* Strongylocentrotus *sp. from 50-60 depth in Kobbefjord collected 7 June 2011.*

lowest recorded for the five-year sampling period showing a decreasing trend. For the scallops, gonad index in 2011 was close to average for the five-year period. The condition index in 2011 showed a new maximum for the scallops and a value close to the previous three years for the sea urchins. Looking at the five-year data set, two trends are apparent, increasing condition index for scallops and decreasing gonad index for sea urchins.

Both indices are calculated as a weight fraction of soft tissue compared to hard parts. For the condition index, all soft tissues are weighed (including gonads) and for the gonad index only gonadal tissue are quantified. Therefore, both indices reflect the energetic state of an individual. Obviously, food conditions are an important driver of inter-annual variation in both conditions indices. The two species obtain the food differently (grazer vs. filter feeder), which is probably why they display different trends during the sampling period. At present, it is, however, not possible to describe the details of this potential relationship.

Benthic flora

The flora of the sea bottom can contribute significantly to the total primary production of shallow coastal waters (Gattuso et al. 2006) as opposed to oceanic systems where phytoplankton is the only type of primary producer. Even shallow coastal high Arctic waters, where ice covers the surface of the sea most of the year, may have a significant benthic production (Rysgaard and Glud 2007, Gomez et al. 2009). Large brown kelps often form a conspicuous part of the macroalgal community in temperate and Arctic coastal areas (Mann 1973, Rysgaard and Glud 2007). This is also the case in the low Arctic Kobbefjord where macroalgal belts extend to maximum depths of about 40 m (Juul-Pedersen et al. 2009).

Kelps of the genus *Laminaria* produce an annual blade, the size of the blade reflects the growth of the preceding year, which depends on light availability and, in Arctic areas, sea ice cover. The size of the annual blade is therefore selected as a monitoring variable. In the high Arctic, the annual growth of sugar tangle, *Saccharina latissima*, can be estimated based on a single sampling in late summer, since the new blade is separated by clear constrictions from the old blade, which may remain for one to two years (Lund 1951, Dunton 1985, Borum et al. 2002). At lower latitudes like in Nuuk, the blades are turned over at faster rates, however, and the tip may be worn off before the annual growth is completed, so the size of the new blade reflects a minimum estimate of annual growth (Juul-Pedersen et al. 2009). In Kobbefjord, *L. longicruris*, which is closely related to *S. latissima*, is dominant while *S. latissima* is absent and the programme therefore targets *L. longicruris* rather than *S. latissima*.

L. longicruris was collected by rake at 7 m depth in the outer, southern part of Kobbefjord 5 August 2011. Thirteen mature specimens having blades longer than 1.5 m was collected at a protected site where sea ice occasionally forms in winter (64°08.408’N; 51°35.158’W) and 15 specimens were collected at an exposed site with no sea ice (64°08.782’N; 51°37.113’W). As *Laminaria* was grazed down by sea urchin at the original exposed sampling site, sampling was moved a few hundred metres closer to the mouth of the fjord in 2010 and 2011.

Annual growth – blade size

Annual growth measured as mean blade length varied from a minimum of 188 cm at the exposed site in 2007 to a maximum of 227 cm at the same site in 2010 (figure 5.23a; left panel). Blade length did not show any trend over the sampling period 2007-2011 and did not differ between sites (figure 5.23a; linear model: $p > 0.05$).

Annual growth measured as blade biomass was more variable, ranging from a minimum of 120 g dw at the protected site in 2007 to a maximum of 198 g dw at the exposed site in 2011. Blade biomass also did not differ between sites, but showed an increasing trend over the sampling period (figure 5.23b; linear model: $p < 0.0001$).

As there were no differences in kelp growth between sites, possible differences in sea ice cover between the sites, thus, did not affect the growth. Growth rates of the kelp in Kobbefjord were, however, high relative to those in Young Sund, NE Greenland, where sea ice covers the fjord 9-10 months of the year (Borum et al. 2002).

The apparent increase in blade biomass over the sampling period is probably an artefact influenced by the low values recorded in 2007, which are likely related to the later sampling that year (September) than the following years (August). Later sampling likely increases the risk of blade erosion by autumn storms and may also cause a larger part of the biomass to be lost as spores.

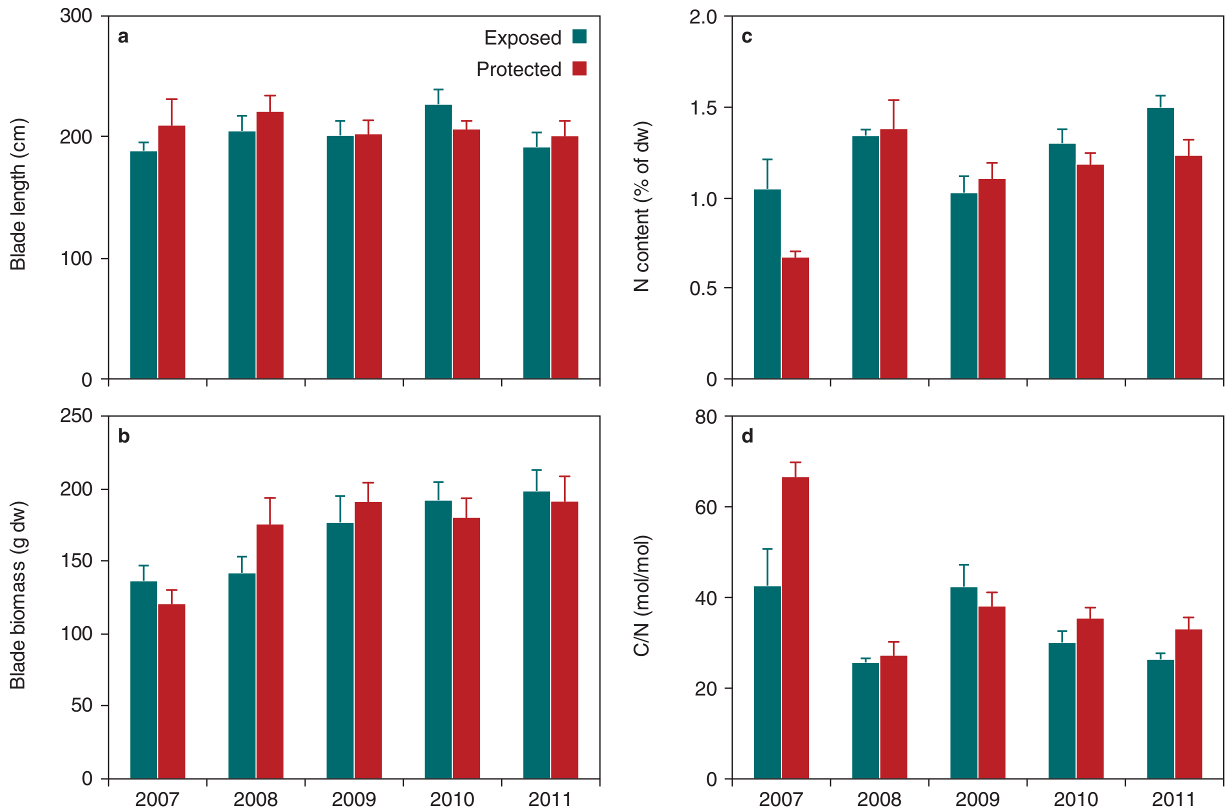
Nitrogen content and C/N ratio of kelp blades

The mean N-content of kelp blades varied considerably from a minimum of 0.67% at the protected site in 2007 to a maximum of 1.50% at the exposed site in 2011 (figure 5.23c). The N-content did not show any significant trend over the years but was significantly higher at the exposed site than at the protected site (linear model: $p = 0.0395$).

The C/N-ratio of the blades also varied considerably, ranging from a minimum of 26 at the exposed site in 2008 to a maximum of 67 at the protected site in 2007 (figure 5.23d). There was an overall negative trend in C/N-ratios over the period and significantly higher ratios at the protected site relative to the exposed site (linear model: $p < 0.0001$ and $p = 0.0056$, respectively).

The nitrogen content reflects the balance between demand and supply. During winter, when the supply of inorganic nutrients is relatively high and the demand is low, nitrogen reserves build up. During

Figure 5.23 a) Length, b) biomass, c) nitrogen content and d) C/N ratio of blades of mature Laminaria longicruris *with blade lengths larger than 1.5 m collected at a protected and an exposed site in Kobbefjord in September 2007 and August 2008-2011.*



the following summer when the demand is high and the supply low, the reserves are drained. Release of spores may exert an extra drain on the N reserves in late summer. Nitrogen concentrations are therefore likely to reach a minimum by the end of summer. Carbon concentrations, by contrast, are likely to be highest in late summer, as carbohydrates have been built up by photosynthesis over the summer. These mechanisms may explain the generally lower N content and higher C/N-ratio in the September sampling of 2007 relative to the August samplings of 2008-2012, which generates the overall negative trend (figure 5.23d). The generally higher N-content and lower C/N-ratio at the exposed site relative to the protected site may be related to the larger flushing and thus higher nutrient supply and lesser sedimentation on the blades.

With five years of data, the last four representing August, we see that the blades of the kelp vary around a mean length of about 2.1 m, a biomass of 181 g dw, a nitrogen content of 1.3 % dw and a C/N ratio (molar) of 32 at the two sites (mean of the last five years of data). As blade growth apparently does not reflect the expected differences in sea ice cover between sites, quite large variations in growth conditions are likely needed to identify a significant change in blade size of *Laminaria longicruris*.

5.6 Seabirds

Two major seabird colonies near Nuuk are included in the MarineBasis programme. Additional seabird colonies in the Nuuk area have been visited since 2007. Amongst them, the kittiwake *Rissa tridactyla* colonies of Godthåbsfjord (five in total) were surveyed and the results are included in this report. The seabird counts from MarineBasis are reported annually to the Greenland Seabird Colony Database maintained by the Department of Bioscience, Aarhus University (http://www.dmu.dk/Greenland/Olie+og+Miljoe/Havfuglekolonier).

Qeqertannguit (colony code: 64035)

Qeqertannguit in the interior parts of Godthåbsfjord (figure 5.1) is a low-lying island and holds the largest diversity of breeding seabirds in the Nuuk area. Especially surface feeders such as gulls (*Laridae*), kittiwake and Arctic tern *Sterna paradisaea* are well represented at the site (table 5.3). The steep cliff in the middle of the southeast facing side of the island (kittiwake and Iceland gull *Larus glaucoides*) and a smaller cliff on the north facing side (Iceland gull) were counted 23 May (early in the incubation period) from the sea using a boat as platform. Counts of the remainder of the island were conducted by foot 13 June using direct counts of Apparently Occupied Nests (AON) and territorial behaviour as a criterion of breeding pairs. The land-based

Table 5.3 Breeding seabirds pairs (P), individuals (I) or Apparently Occupied Nests (AON)) at Qeqertannguit since 2006.

Year	2006		2007		2008		2009		2010		2011	
Species	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**	**No.**	**Unit**
Black-legged kittiwake	45	AON	45	AON	20	AON	55	AON	42	AON	80	AON
Iceland gull SE side	118	AON	82	AON	33	AON	40	AON	31	AON	31	AON
Iceland gull NV side	–	AON		AON*	12	AON	19	AON	13	AON	20	AON
Great black-backed gull	46	P	38	P	44	P	24	P	40	P	17	P
Lesser black-backed gull	10	P	11	P	25	I	21	I	27	I	18	I
Glaucous gull	10	P	14	P	13	P	5	P	4	P	2	P
Herring gull	-	P	1	I	2	P	1	P	0	P	0	P
Arctic tern	150-220	I	150	I	0	I	150	I	54	I	50	I
Arctic skua	2	P	2	P	2	P	2	P	2	P	0	P
Black guillemot	615	I	562	I	689	I	637	I	790	I	1047	I
Red-throated diver	1	P	1	I**	1	P	1	P	0	P	0	P
Red-breasted merganser	observed		4	P	3	P	0	P	1	P	0	P

*These birds are included in the number for SE birds
**Seen at the coast, but the lake was dry and no nest was visible

Table 5.4 Counts of breeding seabird (all given as number of individuals) at Nunngarussuit since 2006.

Year	2006	2007	2008	2009	2010	2011
Species	**No.**	**No.**	**No.**	**No.**	**No.**	**No.**
Guillemot unspecified	694	–			–	514
Brünnich's guillemot	–	705	388	475	–	–
Common guillemot	–	87	36	47	–	–
Guillemots on the water	2–300	450	450	–	–	500
Glaucous gull	20	14	14	12	–	11
Great black-backed gull	5	5	2	5	–	4
Northern fulmar	23	13	17	11	–	21

survey was carried out a little later than previous years because of the late snow melt.

Other birds observed (not considered breeding or not systematically censused) 23 May included five pairs of long-tailed ducks *Clangula hyemalis* and two great cormorants *Phalacrocorax carbo* seen from the boat. On 13 June during walk, one common gull *Larus canus*, one female long-tailed duck, one pair (potential breeders) of common eider *Sommateria mollissima*, three pairs (potential breeders) of mallard *Anas platyrhynchos*, one pair of Canada goose *Branta canadensis*, one razorbill *Alca torda*, one ptarmigan *Lagopus mutus* and two ravens *Corvus corax* were observed. The ravens were not heavily harassed by the gulls, which can be a sign of little reproduction success of the gulls (Lars Maltha Rasmussen pers. comm.). About 50 Arctic terns were observed at the south end of the island 23 May but none was observed breeding 13 June. The colony was not revisited later in the season to see if they actually bred this year.

The number of breeding kittiwakes was the highest since before 2006, whereas the number of Iceland gulls appeared to be at a similar level as previous years. The gull species breeding in the terrain were all breeding in lower numbers than previous years. There were rumours about a fox observed on the island but the low number could also be related to the late snow melt. For the first time no Arctic skuas were seen during the survey. The number of Arctic terns has generally been low in recent years and breeding has not been confirmed since 2009 where one nest was found (table 5.3).

Qeqertannguit is influenced by legal egg harvesting (great black-backed gull and glaucous gull *L. hyperboreus* prior to May 31) and illegal egg harvesting (after May 31 and of species where no egg collecting is permitted e.g. Iceland gull, lesser black-backed gull *L. fuscus*, herring gull *L. argentatu*) has been reported several times since the start of the monitoring programme. In 2011, a new climbing rope for egg collection was removed from the kittiwake/Iceland gull breeding area 30 May, the rope having been placed after 23 May.

Nunngarussuit (colony code: 63010)

Nunngarussuit is located approximately 40 km south of Nuuk (figure 5.1). The north facing cliff wall of the small island holds the only colony of guillemots *Uria* sp. in Nuuk area (the colony includes both Brünnich's *Uria lomvia* and common guillemot *U. aalge*). These alcids are deep divers preying on fish and large zooplankton. Both direct counts and photo counts of birds present on the cliff were conducted from the sea (boat) 7 July (table 5.4). The number of guillemots on the water was estimated to about 500 individuals. The number of guillemots (both species) on the cliff was similar to 2009 and a little higher than in 2008.

In order to address the proportion of the boreal distributed common guillemot versus the Arctic Brünnich's guillemot in the colony, an analysis of digital photographs is usually carried out. This is interesting in the context of climate change where the proportion of common guillemot could be expected to increase in a warmer climate (table 5.4). Unfortunately, it was not possible to make a proper classification of the two species due to difficult conditions for photography.

Other seabird observations near Nunngarussuit

Simiutat (63011) 7 July: Due to rain and high sea only one of the Simiutat islands was visited. Following was observed: 30

puffins *Fratercula arctica*, eight razorbills *Alca torda*, six adult glaucous gulls, four adult great black-backed gulls, one lesser black-backed gull, one herring gull *Larus argentatus*, one hybrid glaucous/great back-backed gull, four male common eiders *Somateria mollissima*, 10 female common eider (two of them with a clutch) and one resting peregrine falcon *Falco peregrinus*.

Qarajat qeqertaat (63019) 7 July: The site consists of two islands with breeding common eiders. Unfortunately, rain prevented a prober count of nests to be carried out.

Other kittiwake colonies in the Nuuk fjord (see the Seabird database for details)

The number of kittiwakes and Iceland gull at the four remaining kittiwake colonies in the Nuuk fjord, are listed in table 5.5 including counts since 2006.

The total number of kittiwakes of the four colonies has since 2007 shown a somewhat different pattern than the Qeqertannguit colony, but the 2011 counts showed a similar general increase in the number of breeding kittiwakes. Only Alleruusat had fewer breeders this year than the year before, whereas Innajuattoq in particular showed a notable increase.

The numbers of Iceland gulls recorded since 2007 are more difficult to interpret, since they have been given in different units, but numbers of breeders of this species at Innajuattoq were also shown to be notably higher in 2011 than previous years. Some of the Iceland gulls at this colony occupy areas high above sea level where nests can be difficult to see from the boat, and former numbers may have been underestimated. In 2011, a complete photo survey of this colony was carried out for the first time. The number of breeders in 2011 was almost as high as the former total number of individuals and it is expected that the increase in the number breeders is real.

Remaining species in the four colonies observed in 2011 were:

- Innaarsunnguaq (64015): 56 razorbills and four great cormorants (not breeding) 23 May.
- Kangiusaq (64018): Black guillemots?
- Alleruusat (64022): 11 adult (three on nest) great cormorants, two juveniles (brown) and nine unspecified flying off 1 June.
- Innajuattoq (64019): 29 black guillemots, eight great cormorants on nests 14 June.

5.7 Marine Mammals

West Greenland is a summer feeding ground for humpback whales *Megaptera novaeangliae* (Pomilla and Rosenbaum 2005). Most of them stay on the off-shore banks, but some visit the fjords and bays to feed on zooplankton and capelin *Mallotus villosus* (Heide-Jorgensen and Laidre 2007). Some of these whales have a high degree of site fidelity to Godthåbsfjord and return year after year to feed (Boye et al. 2010). In the MarineBasis monitoring programme we use photo-identification to estimate the number of humpback whales feeding in Godthåbsfjord each summer

Table 5.5 Counts of breeding kittiwakes and Iceland gulls at the remaining four kittiwake colonies of Nuuk fjord system. (I) = individuals.

Year	2006	2007	2008	2009	2010	2011
Kittiwake						
Innaarsunnguaq (64015)	240 (I)	62	33	12	16	27
Kangiusaq (64018)	–	217	450	284	370	509
Alleruusat (64022)	–	276	369	164	260	175
Innajuattoq (64019)	–	302	309	458	375	731
Sum	**–**	**857**	**1161**	**918**	**1021**	**1442**
Iceland gull						
Innaarsunnguaq (64015)	1580 (I)	–	961(I)	435	477	518
Kangiusaq (64018)	–	300	494(I)	261	277	262
Alleruusat (64022)	–	45	140	80	100	122
Innajuattoq (64019)	–	342	1497(I)	1553(I)	335/1535(I)	1409
Sum	**–**	**–**	**–**	**–**	**1189**	**2311**

and the turnover of whales during a season to understand how much these top-predators eat and thus affect the Godthåbsfjord ecosystem.

Photo-identification is a technique used to identify individual animals from photographs showing natural markings such as scars, nicks and coloration patterns (Katona et al. 1979). The technique can, in combination with mark-recapture analysis be used for estimating abundance of marine mammals in specific areas. Photo-identification is also used to investigate residence time (i.e. how long the animals stay in a given area) and site fidelity (i.e. individuals returning to an area in different years) (e.g. Bejder and Dawson 2001). In humpback whales, the ventral side of the fluke is used for identification as the tail contains individual colour patterns, which in a way is comparable to human fingerprints (figure 5.24).

Photo-identification pictures were taken with a 350 EOS Canon camera with a 300 mm Canon lens. In addition to dedicated surveys, guides on the local whale tourist boats and the public kindly contributed with identification-photos. The dedicated surveys were carried out twice a week from May to September 2011 from small research boats.

A total of 119 ID pictures were collected in Godthåbsfjord in 2011 from which 19 different whales were identified (table 5.6). Of the identified whales 58 % had been identified previously (2007-2010) in the fjord and 31 % of the whales identified in 2011 had also been identified in 2010. In the period 2007-2011 a total of 297 identification pictures were taken and with these, a total of 100 individual whales have been identified in Godthåbsfjord (table 5.6).

The re-identification rate between subsequent years varies between 20-50 %. This variability from year to year is most likely the effect of annual variability in sampling effort and whale distribution. It is therefore too early to give any conclusive estimate of re-identification rate.

The results confirm that individual whales have a high degree of site fidelity to Godthåbsfjord. The individuals with the highest degree of site fidelity are also the individuals staying within the fjord for the longest periods of time during the feeding period (figure 5.25). E.g., an individual that has returned to the Godthåbsfjord five years in a row was on average encountered about eight times per year. In

Figure 5.24 Ventral side of a humpback whale fluke, photographed in Godthåbsfjord. Photo: GINR Whale Photo-ID catalogue.

Table 5.6 Humpback whale site fidelity to Godthåbsfjord in 2007-2011. Percentage of whales (within 2007-2011), identified in a given year and re-identified the following year. E.g. six of the 20 whales identified in 2008 were also identified in 2009 (30 %).

				Whales re-identified the following year			
Year	**#IDs**	**Identified whales**	**New individuals**	**2008**	**2009**	**2010**	**2011**
2007	49	20	20	8 (40)	6 (30)	7 (35)	5 (20)
2008	143	20	12	–	6 (30)	10 (50)	7 (35)
2009	38	15	8		–	7 (47)	6 (40)
2010	68	26	13*			–	8 (31)
2011	119	19	8**				–
Total	**297**	**100**	**61**				

*Includes three whales that were identified in the fjord before 2007, **Includes one whale that was identified in the fjord before 2007

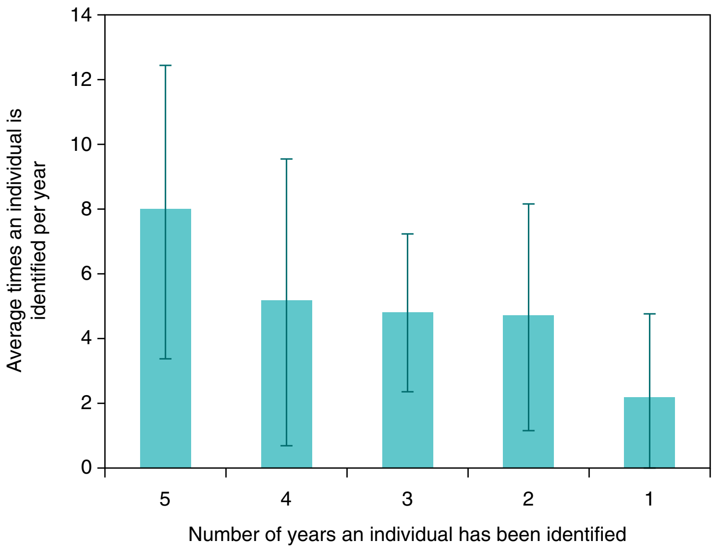


Figure 5.25 The average times individual humpback whales are identified relative to the number of years the individual has been identified in Godthåbsfjord.

Figure 5.26 Example of a humpback whale photographed in Godthåbsfjord in June 2008 (top) and in Disko Bugt in August 2008 (below). The same individual was also identified in Disko Bugt 2007 and 2009. Photo: GINR Whale Photo-ID catalogue.

contrast, an individual that has only been observed in the fjord one year was only encountered twice during that year.

In Godthåbsfjord, between 20 and 50 individuals are encountered each year. Photos collected in Disko Bay also provide information on the whales we encounter in Nuuk. The concurrent photo-identification effort in the two areas has shown that some humpback whales visiting Godthåbsfjord are also encountered in Disko Bay. An example of such a re-sighting is shown in figure 5.26. The movement of humpback whales between feeding areas within the West Greenlandic feeding ground was first shown by two satellite tagged humpback whales that used several feeding areas within Davis Strait and West Greenland during the same summer (Heide-Jørgensen and Laidre, 2007).

6 NUUK BASIC

Research projects

6.1 Seasonal study on benthic metabolisms in a low Arctic area

Heidi L. Sørensen, Lorenz Meire, Karl Attard, Thomas Juul-Pedersen, Bo Thamdrup, Søren Rysgaard, Dan McGinnis, Filip Meysman and Ronnie N. Glud

The benthic metabolism is mainly controlled by the amount and condition of the organic material transferred to the sea bed (Sagemann et al. 1998; Thamdrup and Fleisher 1998). Consequently, the strong seasonal pattern in organic material transfer influences the benthic dynamics (Therkildsen and Lomstein 1993). In the high Arctic regions, sea ice cover restricts the transfer of organic material to the sea bed to a few months (Subba Rao and Platt 1984). In low Arctic regions, however, the transfer of organic material is less restricted. Thus, the benthic metabolism patterns vary significantly at different longitudes. This study aims to evaluate the seasonal dynamics in a benthic low Arctic system and to study to what extent the variation in productivity and sedimentation is reflected in the degradation pathways and the overall degradation efficiency. Through this, one can be provided with an estimate of how conditions in the high Arctic may transform under the predicted climate changes for the region. The ongoing study was initiated in spring 2011 and is planned to continue until summer 2012.

Core incubations are used to quantify the total exchange of oxygen, CO_2 and nutrients. The collected cores are also used for porewater profiles of oxygen, pH, DIC, sulphate, iron, nitrate and ammonia, and process rates of sulphate reduction, denitrification and anammox (Klimant et al. 1997, Kostka et al. 1999, Kallmeyer et al. 2004, Rysgaard et al. 2004, Trimmer et al. 2007).

Next to core incubation, also eddy correlation is used. Using oxygen as a proxy for the overall mineralization rates, oxygen eddy correlation is used to measure the oxygen exchange across the sediment water interface during day and night for a period of four to five days. In this way, mineralization and photosynthesis can be assessed in different locations, also in locations with a hard bottom substrate where core incubations are impossible (Glud et al. 2010).

Preliminary results indicate only a slight seasonal variation in benthic metabolism. A peak in pelagic primary production was observed in May; however, oxygen uptake did not appear to change significantly. Sulphate reduction rates (SRR) increased from August, which could indicate an increase

Figure 6.1 Sediment sampling in Kobbefjord. Photo: Karl Attard.

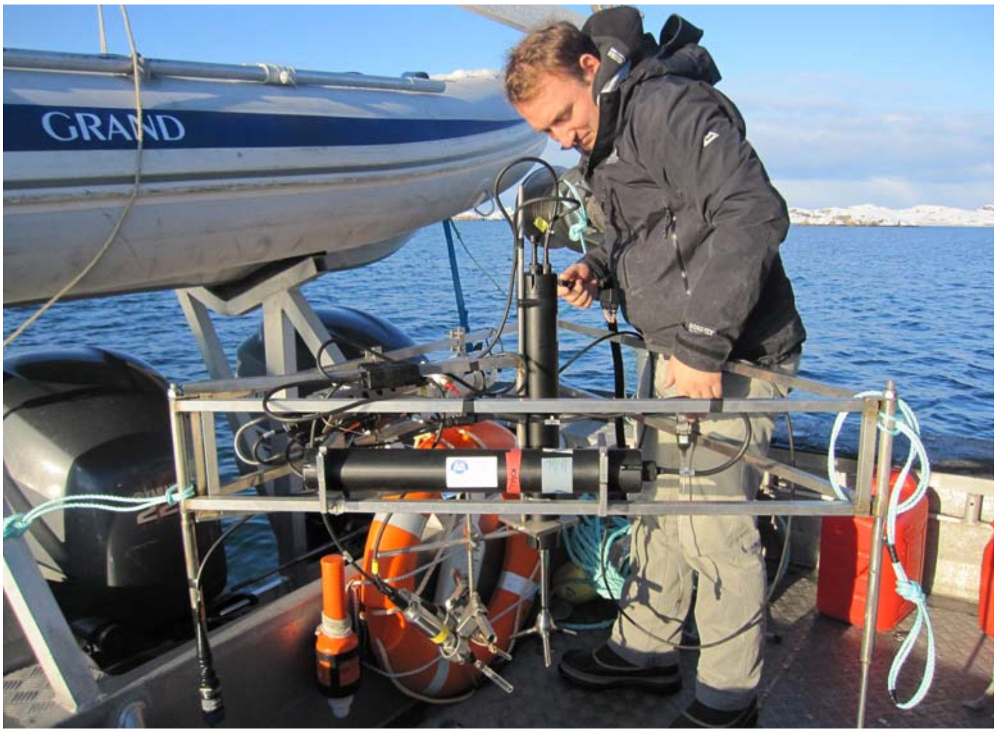


Figure 6.2 Karl Attard deploying the aquatic eddy correlation system in Kobbefjord. Photo: Lorenz Meire.

Figure 6.3 Studying and subsampling a sediment core cut in half. Photo: Niels Nørgaard-Pedersen.

in available substrates. Denitrification rates seem insignificant as it only accounted for approximately 7% of the total carbon oxidation in the sediment. Monthly Respiration Quotient (RQ) indicated a higher uptake of oxygen compared to CO_2 release, which could indicate a build up of reduced equivalents in the sediment. This is further supported from the increased SRR, where H_2S is produced. Thus, following the spring bloom oxygen is mainly used to degrade organic material transferred to the sea bed, whereas oxygen later on primarily is used to re-oxidize reduced compounds. Comparing these results to the extensive studies made at Young Sund, NE Greenland, where benthic metabolism activity increase is observed for a few months, benthic metabolism seems steady in Kobbefjord, West Greenland.

6.2 Settlement patterns in Godthåbsfjord – an interaction between Humans and Ice

Ann Eileen Lennert, Niels Nørgaard-Pedersen, Naja Mikkelsen, Christian Koch Madsen and Søren Rysgaard

When speaking about climate changes, it is either described as an improvement in the climate, a mildening or as a worsening of the climate often associated with colder climate. There is no doubt that these terms can be put in perspective when speaking about climate change in the Arctic but there is also no doubt that these terms and the result of climate changes influence cultures in different ways.

The project ‘Settlement patterns in Godthåbsfjord, an interaction between Humans and Ice’ is an interdisciplinary study where environmental reconstructions based on marine geology, satellite imagery and oceanographic data, ecosystem variations, archaeological material and cultural analysis are interpreted, supplementing each other.

In connection with this project, and as a link to a new project 'The Norse settlements at the eastern side of Kangersuneq, – an interdisciplinary analysis of Norse interaction with changing landscapes and ice', starting summer 2012, and the National Museum of Greenland project 'Alle tiders mennesker, kulturminderne i Grønland og den globale klimaændring', a winter survey was organized. Here an insight of the Norse and the winter landscapes was in focus, concentrated upon related issues such as maintenance of communication between Nunatartsuaq's isolated farms and the rest of the western settlement. What opportunities and obstacles are established by the winter landscape's snow and ice? The projects are carried out in order to get a broader understanding of the relation of Humans and Ice, and the consequences and benefits of a changing landscape.

6.3 Ice dammed lake drainage in Godthåbsfjord

John Mortensen, Kunuk Lennert, Søren Rysgaard, Jørgen Bendtsen, Kristian K. Kjeldsen, and Dorthe Petersen

A recent cooperation between Centre for GeoGenetics, Natural History Museum at University of Copenhagen and Greenland Climate Research Centre at Greenland Institute of Natural Resources have added new knowledge on the detection and impact of ice dammed lake drainage in fjords. Drainage of ice dammed lakes is detected by satellites, less often by photographs, and by river measurements. In-water observations of these drainage events in adjacent coastal waters have not yet been reported. Here we present the first direct hydrographic observations of pulses of freshwater produced by rapid ice dammed lake drainage, passing a mooring located just below the intertidal zone in a low Arctic fjord. Satellite observations of this particular glacier demonstrate that the ice dammed lakes drain periodically, and on-going thinning of the glacier suggests that drainage events will become more frequent in a future warmer climate. The drainage of ice dammed lakes is observed as a characteristic sequence of changes in temperature and salinity at the mooring site: i) decrease in temperature, ii) followed days later by increase in salinity and temperature, and iii) properties return to undisturbed seasonal level. The drainage events in 2009 are all observed in conjunction with an abrupt increase in surface layer salinity at the mooring site. The salinity increase can be explained by relatively large entrainment and mixing between the subglacial freshwater outflow and saline deep water at the tidal outlet glacier.

Figure 6.4 Remaining icebergs in the empty lake Ujarattooq in September 2009. Note the person in the foreground. Photo: Thomas Juul-Pedersen.

A follow up research project with the title 'Mooring network for monitoring ice dammed lakes drainage in Godthåbsfjord' have been financially supported by INN and Greenland Climate Research Centre with start in 2012. The purpose of the project is to improve knowledge of the dynamics of the drainage pulses within the fjord.

6.4 Mercury (Hg) transport from the terrestrial to the marine environment

Frank Rigét, Mikkel Tamstorf, Martin M. Larsen, Jens Søndergaard and Karl Martin Iversen

Inputs of mercury (Hg) to the environment comprise both natural and anthropogenic sources. Hg is present in the Earth's crust, mainly in the mineral cinna-bar (HgS), and Hg is released in natural processes such as weathering of rocks and volcanic/geothermal activity (AMAP 2011). Anthropogenic Hg emissions come mainly from fossil-fuel fired power plants, small-scale gold mining, cement production and metal manufacturing (AMAP 2011). Global Hg emissions are likely to increase in the future (Streets et al. 2009) and predicted climate variations in the Arctic are likely to influence Hg pathways.

Hg transport was studied in the Kobbefjord river during summer 2009 and 2010. Water was sampled at a location near the river mouth typically every three or four days. In total, 45 samples were collected in 2009 and 47 samples in 2010. The chemical analyses method is described in Jensen and Rasch 2010.

Figure 6.5 shows the Hg concentrations in river water throughout the 2009 and 2010 seasons. The red line represents the loess (local polynomial regression) smoother line. Hg concentrations in the Kobbefjord river ranged from <0.1 to 1.0 ng l^{-1} but was typically between 0.2 and 0.6 ng L^{-1}. The highest Hg concentrations were measured during spring in 2009 and the average Hg concentrations (±SD) for 2009 and 2010 were 0.46±0.17 ng l^{-1} and 0.26±0.17 ng l^{-1}, respectively. Daily discharges of Hg from the Kobbefjord river were highest (up to 0.5 g day^{-1}) during spring in 2009 and 2010 and during pe-riods with heavy rain. A total of 29 and 26 million m^3 of water was discharged from the river during 2009 and 2010, respectively.

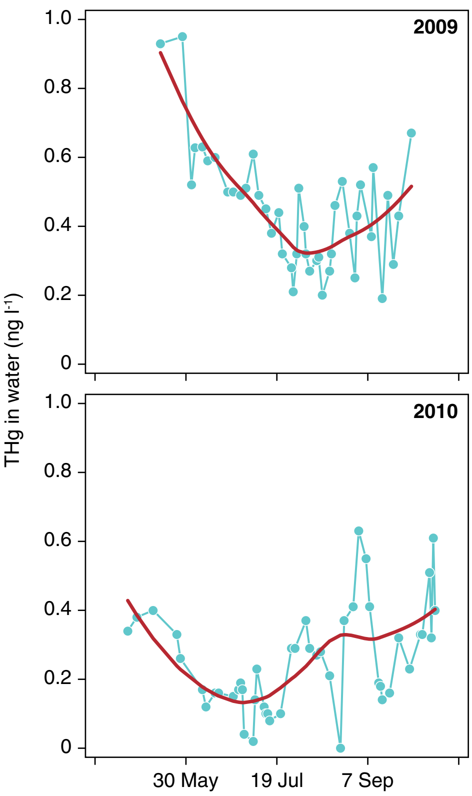


Figure 6.5 Hg concentrations in river water during the summer period in 2009 and 2010. Red line represents loess (local polynomial regression) smoother line.

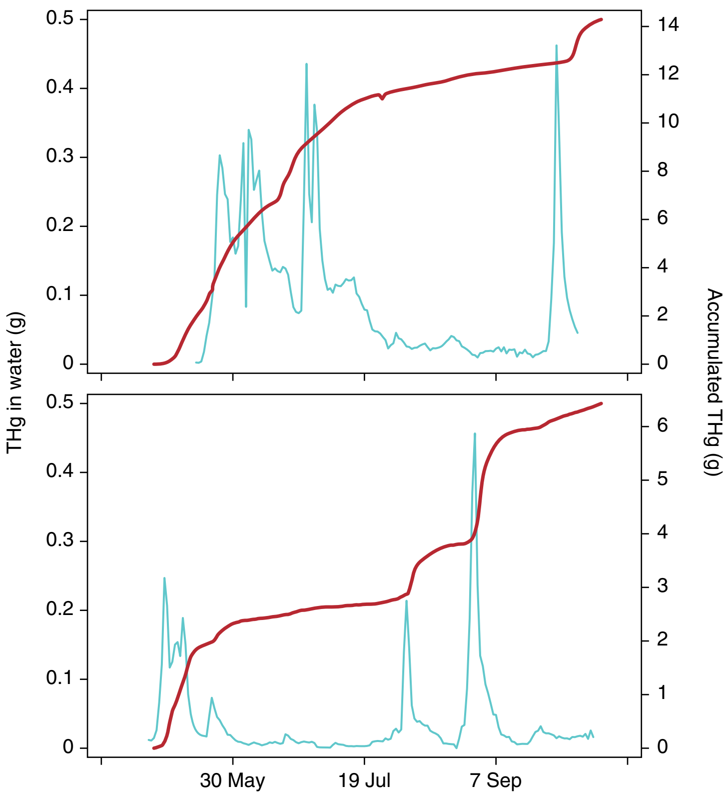


Figure 6.6 Daily amount of Hg (blue) and the accumulated amount throughout the summer (red) for Kobbefjord River in 2009 and 2010.

The daily discharge of Hg followed closely the daily water discharge (figure 6.6). The total Hg release from Kobbefjord river was estimated to 14 g for 2009 and 6.4 g for 2010. The early season release of Hg in Kobbefjord river is mainly considered the result of Hg deposited on the ground or snow surface during the six-month winter period (November-April), which is flushed out during snow melt.

6.5 Climate effects on land-based ecosystems and their natural resources in Greenland

Mads C. Forchhammer, Jacob Nabe-Nielsen, Torben L. Lauridsen and Erik Jeppesen

A research project at the Greenland Climate Research Centre focuses on collating existing and new data on terrestrial and limnic ecosystems in order to describe and analyse the effects of local and regional changes in climate on the land-based ecosystems and their natural resources. As part of the project, a large field campaign was implemented in the Nuuk area in 2010 and continued in 2011 with transect sampling of terrestrial and limnic stations along Godthåbsfjord.

The terrestrial component

In July 2011, vegetation types and plant diversity were sampled at four permanent stations along Godthåbsfjord (figure 6.7) selected among the 12 sites visited in 2010. At each of the four stations, vegetation was investigated using pin-point analyses on an altitudinal gradient 20, 100, 200, 300 and 400 meters above sea level. In total, 180 pin-point plots were sampled. Preliminary results demonstrate a clear east-west as well as an altitudinal gradient in the species compositions of the vegetation types along Godthåbsfjord. We expect these tendencies to become more pronounced when the last plots have been established. Permanent markings references using differential GPS will ensure the long-term use of these plots.

Large-scale defoliation of shrubs by *Eurois occulta* larvae has been reported before in West Greenland. However, not withstanding its tremendous effect on the annual growth of vegetation, the frequency by which it occurs has not been analysed

Figure 6.7 Vegetation types and plant diversity are studied at four permanent stations along Godthåbsfjord.

in detail before. To this end, we are in the process of carrying out spectral analyses of up to 100-year long time series of annual growth of shrubs sampled, not only in the Godthåbsfjord area, but throughout Greenland. Incidentally, in 2011, most plants, but *Salix glauca*, *Betula nana* and *Vaccinium uliginosum* in particular, were found defoliated by larvae at most of our stations. The degree of defoliation was incorporated into our pin point sampling for future detailed analyses of this apparently recurring event.

The limnic component

In August 2011, researchers from Turkey, Uruguay, England and Denmark investigated 18 lakes close to the bottom of Godthåbsfjord, more specifically at locations east and west of Ujaragssuit. Focus was to give a general description of the physical, chemical and biological conditions and to identify the predominant trophic interactions in the lakes. The locations varied from shallow coastal lowland lakes at an altitude of approximately 50 m a.s.l. to deep mountain lakes at an altitude of 360 m a.s.l. The lakes investigated varied in size from 0.3 to 125 ha and depth ranged from 1.3 in the smallest lowland lake to a maximum of 54.5 meters in one of the high altitude lakes. Except for one small lake, all lakes had high clarity and a maximum visibility of 19.1 m in the deepest high altitude lake.

An important factor for lake status and trophic interactions in lakes is fish. The predominantly high altitude of the lakes meant that only six lakes were inhabited

Table 6.1 Morphometric and physico-chemical parameters from the 13 lakes in 2010.

Lake	Area (ha)	Altitude (m a.s.l.)	Max depth (m)	Secchi depth (m)	TP (mg l^{-1})	TN (mg l^{-1})	Conductivity (mS m^{-1})
No 1	4.7	12	12.6	–	0.007	0.37	4.6
No 2	3.2	44	3.6	> 3.6	0.005	0.21	4
No 3	1	53	3.5	> 3.5	0.008	0.23	4.1
No 4	0.4	40	1.7	> 1.7	0.008	0.24	4.3
No 5	2.2	27	8.9	8	0.005	0.24	5.4
No 6	0.3	47	0.6	> 0.6	0.01	0.35	2.9
No 7	2.4	61	1.3	> 1.3	0.004	0.26	3.8
No 8	25	70	13.4	6.5	0.004	0.17	4.3
No 9	3.7	82	8.5	6.4	<0.001	0.16	4
No 10	2.6	86	11.5	6.2	0.004	0.14	3.5
No 11	9	96	37	11.5	0.004	0.24	3.9
No 12	75	98	> 85.0	8.2	<0.001	0.1	6.5
No 13	380	97	152	11.5	<0.001	0.13	5.1

by fish, three by both Arctic char and three-spined stickleback, and three lakes by only three-spined sticklebacks. The total catch varied between 4-69 fish per net per night; the highest catch was registered in lakes inhabited by three-spined sticklebacks. Catch of Arctic char varied between 5-13 fish per net.

The lakes sampled in 2010 at Nordlandet were, as expected, highly oligotrophic (table 6.1). Maximum total phosphorous and nitrogen concentration in lake water were 0.01 and 0.37 mg l^{-1}, respectively. Correspondingly, conductivity was low, varying between 2.9 and 6.5 mS m^{-1} (table 6.1). The biological samples from 2010 showed that the macroinvertebrate fauna from lake sediments almost exclusively consisted of chironomids; however, the abundance varied considerably among the sampled lakes. In a few lakes with no or very few fish, remains of *Lepidurus arcticus* were encountered as expected from previous investigations of Arctic lakes and waterholes, indicating a strong impact of fish on the biological components in Arctic systems.

For further updated information as the project continues in 2012 and 2013, please visit the projects Facebook page: (http://www. facebook.com/pages/GCRC-Projekt-6502-Landbaserede-okosystemer-ressourcer-og- klima-i-Gronland/127979750567866).

7 Disturbances in the study area

Josephine Nymand

The study area at Kobbefjord is situated approximately 20 km south-east of Nuuk and can be reached by boat within half an hour. It is a public area and admittance is free to anyone.

Public disturbances fall in the following categories:

- Visits by boats at the bottom of the fjord – no landing
- Visits by boats at the bottom of the fjord – the persons take a short walk inland and returns within a few hours or less.
- Visits by boats at the head of the fjord – the persons go on land and spend the night in a tent close to the coast.
- Hiking through the area – there is a hiking route from Nuuk to the inland passing through the area.
- Visits by snowmobile – during winter people visit the area from Nuuk.
- Ordinary flights by fixed winged aircrafts passing over the study area in cruising altitude or in ascent or descent to or from Nuuk.
- Helicopter flights at cruising altitude passing over the study area.
- The electrical power transmission line between Nuuk and the hydropower plant in Buksefjord runs through the area.

In 2011, there were only few interactions between visitors in the study area and the different setups and the research cabin. There was an attempted break in at the research cabin in August 2011. Foxes have been moving and taken pittfall traps and laying droppings in the pittfall traps.

The monitoring programme itself has brought disturbance to the area i.e. transportation between Nuuk and the bottom of the fjord, housing of personnel, walking between study plots and around study plots. Especially the permanent plots in the *Empetrum* heath and in the fens have signs of wear.

Transportation between Nuuk and the study site in Kobbefjord has been conducted on a irregular basis, but during most of the season there were transport two or three times a week (Tuesdays and Thursdays in one week and Mondays, Wednesdays and Fridays in the next week). During most of the season, the research cabin was used by two to four persons. On a few occasions more than 10 people stayed overnight for one or two nights.

Walking around the study plots has had a wearing effect on the vegetation and it should be considered to mark permanent trails between the research cabin and study plots. Portable boardwalks will be used in the future, especially around the CO_2 flux measuring plots.

When the bridge was built a few helicopter slings were made from Nuuk to the Kobbefjord area with the base construction and materiel. Two carpenters worked on the construction of the bridge for two days; in spite of the relatively large construction the impact on the area was very low. There were no signs of wear around the construction.

In conclusion, it is estimated that monitoring activities only had minor impact on the vegetation and the terrain.

8 Logistics

Henrik Philipsen

In 2011, Greenland Institute of Natural Resources took care of the logistics related to Nuuk Basic in the Kobbefjord area.

The 2011 field season in the Kobbefjord area started 11 January and continued until 12 December. During this period 33 scientists and logisticians spent 199 and 18 'man-days' in the study area, respectively.

The winter 2010/2011 was relatively mild with ice one mile out from the bottom of Kobbefjord. It was possible to sail to the bottom of Kobbefjord from 28 April to 4 November.

Greenland Institute of Natural Resources carried out transportation of staff, technicians, scientists and guests from Nuuk to the Kobbefjord area with the boats 'Aage V. Jensen II Nuuk' and 'Erisaalik'. The total number of sailing days to the Kobbefjord area used by logisticians, BioBasis, GeoBasis and ClimateBasis was 71 in 2011. MarineBasis used 31 sailing days to go to the study areas in Kobbefjord and Godthåbsfjord.

In 2011, scientists spent 63 bed nights in the research cabin in the Kobbefjord area. In Nuuk, the Nuuk Basic scientists were accommodated in the annex of Greenland Institute of Natural Resources, with 169 bed nights.

Water for drinking and other purposes were taken from the nearby river. Electrical power was provided by two portable 2 kW gasoline generators and a 5 kW diesel generator.

Communication to/from Nuuk was made by Iridium satellite telephones, while local communication within the study area was by portable VHF-radios.

Fuel consumption for the generators was 160 litres of diesel and 700 litres of gasoline.

Freshwater consumption was 2800 litres. A drainpipe for grey household water was connected from 8 June until 26 September.

All garbage (approximately 200 kg) was removed by ship to Nuuk during the season.

16 April 2011, a Eurocopter AS 350 Ecureil B2 helicopter from Air Greenland made one flight with a group of Geo- and ClimateBasis scientists from Nuuk to the Kobbefjord area. The scientists carried out snow monitoring in the area using a skidoo. 18 April 2011, the same helicopter picked up the scientists and flew them to Nuuk.

23 June 2011, a Eurocopter AS 350 Ecureil B2 helicopter from Air Greenland made three slings from Nuuk to Kobbefjord with elements for the bridge across the river Kobbefjord. The bridge was donated by Asiaq – Greenland Survey.

19 August 2011, there was an attempted burglary in the research cabin. The front doors and locks were damaged and replaced in September 2011.

24 November 2011, due to ice in Kobbefjord, a Eurocopter AS 350 Ecureil B2 helicopter from Air Greenland made a flight Nuuk – Kobbefjord – Nuuk with four scientists from Climate Basis and an INTERACT project.

12 December 2011, due to ice in Kobbefjord, a Eurocopter AS 350 Ecureil B2 helicopter from Air Greenland made a flight Nuuk – Kobbefjord – Nuuk with three scientists from an INTERACT project.

The study area in Kobbefjord was during 2011 visited by several honourable guests:

8 June: Tilmann Bünz, Journalist NDR, Germany.

15 June: Johnny Fredericia, Executive Director, GEUS and Per Buch Andreasen, Chairman of GEUS.

1 August: Jesper Madsen, Professor, Department of Bioscience, Aarhus University; Søren Rysgaard, Professor, Greenland Institute of Natural Resources; Brian Bech Nielsen, Dean, Faculty of Science and Technology, Aarhus University and Kurt Nielsen, Vice-Dean of Knowledge Exchange, Faculty of Science and Technology, Aarhus University.

9 August: Lene Kielsen Holm, Chairman of Greenland Institute of Natural Resources, five pH. D students and two teachers from IGERT Dartmouth.

31 August: Kasper Busk, Project Coordinator, Ministry of Education, Research and Nordic Cooperation and 15 high school teachers from Greenland.

21 September: Maria Simonsen, Teacher at Ilisimatusarfik, Education Management, University of Greenland and 16 journalist students from the Nordic countries.

9 Acknowledgement

MarineBasis wishes to acknowledge the crew onboard the R/V 'Adolf Jensen' for their valuable assistance during this year's May cruise. We also thank Anna Haxen, Lars Heilmann, Flemming Heinrich, Kunuk Lennert, Susanne S. Hvass, Sofie R. Jerimiassen, Sascha Schiøtt, Kaj Sünksen, Finn Christensen, Andrzej Witkowski, Diana Krawczyk and Marek Zajaczkowski for field and technical assistance. We would also like to acknowledge Paul Batty, Morten S. Frederiksen, Winnie Martinsen, Peter B. Christensen, Carsten Egevang, Bo Bergstrøm and Ditte M. Mikkelsen for their contribution to the programme in previous years.

BioBasis wishes to acknowledge Elin Jørgensen and Zdenek Gavor for their identification of arthropods used for stable isotope analyses, and Peter Gjelstrup, Habitat Vision, Rønde for identification of selected oribatid mites.

10 Personnel and visitors

Compiled by Lillian Magelund Jensen

Peter Aastrup, Department of Bioscience, Aarhus University, Denmark
Eskild Andersen, Tømrerfirmaet ved Eskild Andersen, Denmark
Per Buch Andreasen, Geological Survey of Denmark and Greenland, Denmark
Christian Bay, Department of Bioscience, Aarhus University, Denmark
Kasper Bentzen, Asiaq - Greenland Survey, Greenland
Jørgen Blytmann, Asiaq - Greenland Survey, Greenland
Tilmann Bünz, Freelance journalist (NDR), Germany
Rasmus Egede, Asiaq - Greenland Survey, Greenland
Johnny Fredericia, Geological Survey of Denmark and Greenland, Denmark
Zdenek Gavor, Department of Bioscience, Aarhus University, Denmark
Hendrik Geisler, Asiaq - Greenland Survey, Greenland
Per Hangaard, Asiaq - Greenland Survey, Greenland
Birger Ulf Hansen, Department of Geography and Geology, University of Copenhagen, Denmark
Peter Hegelund, Greenland Institute of Natural Resources, Greenland
Lars Heilmann, Greenland Institute of Natural Resources, Greenland
Flemming Heinrich, Greenland Institute of Natural Resources, Greenland
Ari Hermann, Asiaq - Greenland Survey, Greenland
Kenneth Hill, Asiaq - Greenland Survey, Greenland
Laila Egede Ignatiussen, Asiaq - Greenland Survey, Greenland
Marcin Jackowicz-Korczynski, Department of Physical Geography and Ecosystems Science, Lund University, Sweden
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Paul Henning Krogh, Department of Bioscience, Aarhus University, Denmark
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Magnus Lund, Department of Bioscience, Aarhus University, Denmark
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Peter Rask Møller, Natural History Museum of Denmark, Denmark
Brian Bech Nielsen, Aarhus University, Denmark
Andreas Westergaard Nielsen, Department of Geography and Geology, University of Copenhagen, Denmark
Kurt Nielsen, Aarhus University, Denmark
Josephine Nymand, Greenland Institute of Natural Resources, Greenland
Lasse Nymand, Greenland Institute of Natural Resources, Greenland
Frans-Jan Parmentier, Department of Physical Geography and Ecosystem Science, Lund University, Sweden
Stine Højlund Pedersen, Department of Geography and Geology, University of Copenhagen, Denmark
Mark Andrew Pernosky, Asiaq - Greenland Survey, Greenland
Dorthe Petersen, Asiaq - Greenland Survey, Greenland
Jonathan N. K. Petersen, Asiaq - Greenland Survey, Greenland
Henrik Philipsen, Greenland Institute of Natural Resources, Greenland
Lars Maltha Rasmussen, Greenland Institute of Natural Resources, Greenland
Katrine Raundrup, Greenland Institute of Natural Resources, Greenland
Søren Rysgaard, Greenland Climate Research Centre, Greenland
Kisser Thorsøe, Asiaq - Greenland Survey, Greenland
Zhendong Wu, Department of Physical Geography and Ecosystems Science, Lund University, Sweden

Please notice that the list of visitors is not complete, as the Greenland Institute of Natural Resources has stopped their registration of visitors.

11 Publications

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Agersted, M.D., Nielsen, T.G., Munk, P., Vismann, B. and Arendt, K.E. 2011. The functional biology and trophic role of krill (*Thysanoessa raschii*) in a Greenlandic fjord. Marine Biology 158:1387–1402. DOI 10.1007/s00227-011-1657-z.

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Jensen, S. 2011. Surface Air Temperature Gradients in Greenland – Identification, quantification and temperature modelling. Master thesis. Department of Geography and Geology, University of Copenhagen. 98 pp.

Juul-Pedersen, T., Rysgaard, S., Batty, P., Mortensen, J., Arendt, K.E., Retzel, A., Nygaard, R., Burmeister, A., Søgaard, D.H., Martinsen, W., Sejr, M.K., Blicher, M.E., Krause-Jensen, K., Christensen, P.B., Marbà, N., Olesen, B., Labansen, A.L., Rasmussen, L.M., Witting, L., Boye, T. and Simon, M. 2011. The MarineBasic programme. In Jensen, L.M. and Rasch, M. (eds.). Nuuk Ecological Research Operations, 4th Annual Report, 2010. Aarhus University, DCE – Danish centre for Environment and Energy, Denmark. 84 pp.

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Appendix

Day-of-year (DOY)

Regular years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

Day-of-year (DOY)

Leap years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366